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The Design and Manufacture of Powder Charges for Supersonic Combustion Trials

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DEFENCE RESEARCH ESTABLISHMENT SUFFIELD

Contract Report
DRES CR 2000-014

March 2000

National Defence Défense nationale

Canada

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102-02346/

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THE DESIGN AND MANUFACTURE OF POWDER CHARGES FOR SUPERSONIC COMBUSTION TRIALS

A Report to the

DEFENSE RESEARCH ESTABLISHMENT SUFFIELD

Prepared under Contract No. W7702-7-R658 / 001 EDM

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September 16, 1998

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The Design and Manufacture of Powder Charges for Supersonic Combustion Trials

1.0 Introduction

The Defense Research Establishment Suffield is planning flight trials of hollow, detonation driven flight bodies. In these trials, the flight body is required to be launched into an explosive mixture of gases.

In flight, strong shock waves form at the inlet and these intersect within the hollow body to initiate detonation of the ingested gas.

A high speed at launch is necessary;

1. in order to generate strong shocks,
2. to properly position the shock intersection point within the hollow body, and
3. to insure that the velocity of the flight body is marginally higher than the gas detonation propagation speed.

When these conditions are met, thrust may be generated and the flight body will function as a propulsion engine.

Within the engine a combustion chamber is not required, due to the fact that the energy input into the ingested gas takes place across a shock front. Thus combustion within the engine is supersonic.

The launch velocity required to bring the engine into operation is about 2000 meters per second. A powder gun of 155 mm caliber, has been selected to shoot the flight body into the gas.

To meet the launch velocity requirement, a two pronged strategy was adopted. The first element of this strategy was to make the flight body as lightweight as is practical, and the second, was to drive it out of the gun using as high a sustained pressure as allowed by the gun strength limits.

This report is concerned with the design and the manufacture of the powder charges for gun launching of these lightweight bodies.

The report is divided into three parts, the first of which deals with the design of the gun propelling charge. This is presented in sections 2.0 through section 8.0.

The second part describes the filling procedures determined for making up these charges in limited quantities. This is covered in sections 9.0 and 10.0.

The manufacture of the propellant bags, the ignition units, and other elements of the charge is detailed in section 11.0 and section 12.0, continuing in appendix A through to appendix D.

A plan for a test firing series, to bring the charge into operation is presented in section 13.0.

Part I Design Considerations

2.0 Some problems associated with high performance charges

We mention below five incidents of misbehavior of gun propelling charges. All of these involved attempts to extract the maximum performance possible.

The first of these occurred in France in 1918, during an artillery bombardment of the city of Paris from a battery of German guns emplaced nearly seventy-five miles away. The guns of this battery were made from naval rifles, sleeved down to 210 mm bore, and extended to 100 calibers length, (i.e. 100 x 210 mm).

The propelling charge for these guns, (described by Miller in Reference 1), is illustrated in Figure 2-1.

The great length of this charge is typical of the propelling charges of high performance gun systems.

On the third day of the bombardment referred to above, the breech end of one of the guns blew off killing seventeen members of the gun crew, (the bombardment however, continued).

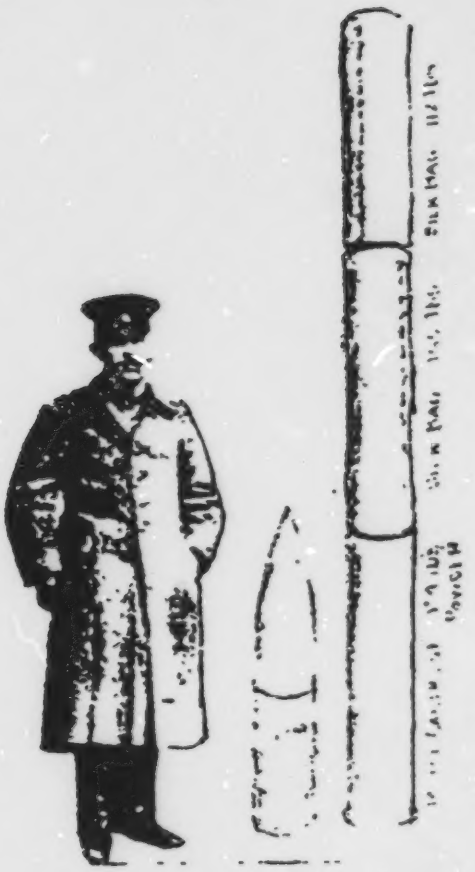
In a more recent example, (1966), at the U.S. Army Aberdeen proving ground, the breech end of a seven inch gun was blown off. The tube survived however, and the gun continued in (experimental) service. This particular gun was employed to vertically fire instrumented projectiles, making atmospheric measurements at high altitudes.

This gun, described by Boyer and MacAllister in Reference 2, was made from a 175 mm rifle, smooth-bored, and extended to 95 calibers in length. The propelling charges employed were approximately twelve calibers in length.

We note again the very long propelling charge, typical of high performance gun systems.

A third such case involved the writer in 1970 while conducting propelling charge development firings. In this instance, the breech blew out of a 155 mm "Long Tom" gun. The charge involved was very large, and the gun was not repairable.

Figure 2-1 A High Performance Charge



RELATIVE SIZES OF THE SHELL AND POWDER CHARGE OF THE PARIS GUN

In a test of a top end charge for a 155 mm - 45 caliber gun, conducted in 1977, the resulting breech blow left the gun in serviceable condition. This gun is shown in Figure 2-2.

The fifth of these examples is a 16 inch diameter smooth bore firing for maximum velocity, this, in preparation for a series of very high speed impact trials. This firing was carried out at the Space Research Corporation test range at Highwater Quebec. The breech end of the gun was blown away and the gun was replaced.

An appreciation into the causes of these intermittent failures was first made in 1965 following the launch of a vertically fired atmospheric probe from a smooth bored 16 inch gun at Barbados, West Indies.

This gun was mounted near the sea shore and fired at an elevation of 85 degrees. The 5 degree forward angle insured that the sabotry and other debris would fall off-shore into the water. Through a series of lucky circumstances a polyethylene disk, used to seal the shot from the propelling gases was carried landward, was recovered, and returned to the project office.

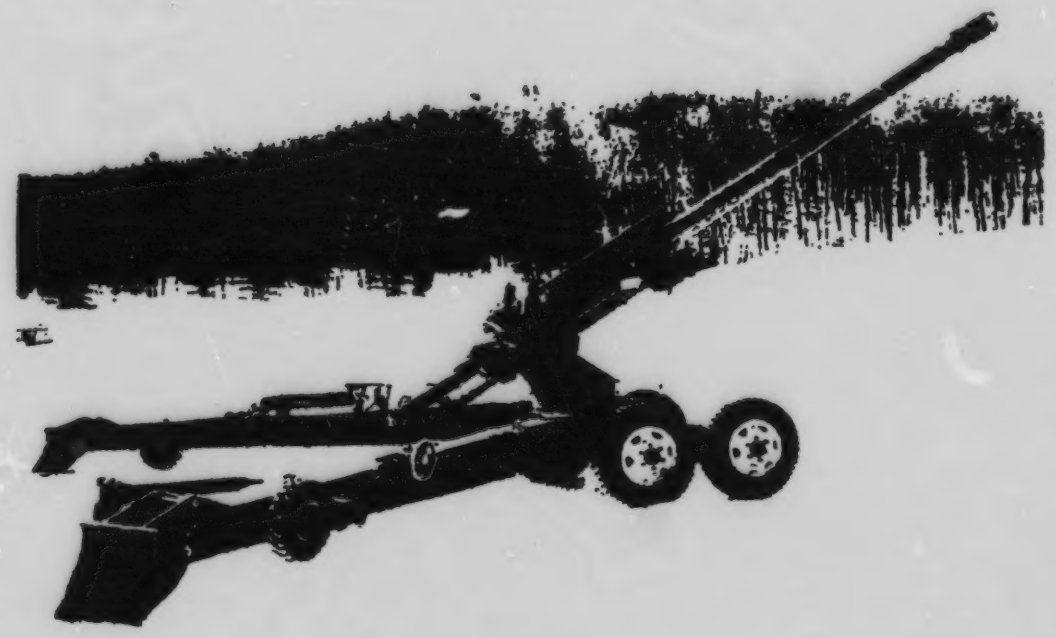
The end of a propellant grain was observed to be imprinted into the seal surface. With this observation came the knowledge that the propellant had, with great force, been driven into the base of the shot.

The propelling charge configuration for this case was comprised of base ignited bags (containing the propellant), initiated by a primer firing through a central vent hole in the breech spindle. The theory drawn from this is that the propellant closest to the breech is ignited first, and evolves into propelling gas, while the propellant forward and nearest the projectile remains in the solid state. The solid propellant is then driven forward into the base of the projectile, where it is broken up into small and irregular pieces. As will be illustrated later, this causes an increase in the rate of burning accompanied by a rapid rise in pressure.

Bull, in Reference 3, suggests that increases in the propellant burning rate may be due to a wave reflection within the powder chamber.

Horst, in Reference 4, indicates the origin of pressure waves within the powder chamber may be due to a strong base ignition pulse.

Figure 2-2 The GC-45 155 mm gun prototype



3.0 The operation of guns for maximum velocity

The energy available for accelerating a projectile to speed is intrinsic to the propellant and depends upon it's composition. The propellant is normally in solid form and is converted (by combustion) into hot gas during confinement in a chamber behind the shot. The rate of burning is dependant mainly upon pressure and can be expressed as follows:

$$R = B.p^{\alpha}$$

where R is the propellant burning rate in inches per second
B is a burning rate constant, fitted to match test results
p is the pressure in pounds per square inch
α is the burning rate exponent

Heavy projectiles are accelerated relatively slowly, and it becomes important to insure that the propellant is not burnt too quickly, since the propelling gas will overfill the volume aft of the shot and produce overly high pressures.

Lightweight projectiles on the other hand, may be accelerated to high speeds. This requires rapid evolution of propelling gas, since the powder chamber volume increases at a very high rate.

Conversion of the solid propellant to gas occurs at high temperatures; this being a characteristic of the composition. The higher energy propellants correspond to the higher temperatures of operation.

The essential conditions to achieve the highest possible velocities at muzzle exit are as follows:

1. The projectile should be of least weight, consistent with post-launch mission requirements.

2. The force applied to the base of the projectile should be as great as possible, subject to the gun mechanical limits.

3. The force applied to the base of the projectile should be applied for as long a time period as possible.

The control of propellant burning to produce propelling gas at the correct rate is dealt with in the sections following.

4.0 Propellant geometry

To examine an important aspect of propellant gas evolution, consider a propellant made into three simple shapes as follows:

1. A sphere.
2. A flat strip.
3. A short rod with 7 equally spaced holes running through it from end to end.

Propellant burns more or less uniformly over the surfaces exposed. The spherically shaped propellant then, will burn for a time until it's outer surface recedes to the spherical center. The time required to burn a charge comprised of spherically shaped propellant grains corresponds to the time required to burn through a distance of half the diameter. The larger the diameter, the longer the burn time.

As an example, consider two charges identical in weight, and each consisted of spherically shaped grains. Now suppose the diameter of the grains of one charge were twice the diameter of the other. The amount of gas produced by each charge will be exactly the same, but the larger grained charge takes twice the time to convert the solid into gas. So we see the time to convert the solid propellant into gas depends upon a dimension of the grain cross section. This is referred to as the propellant web size.

Another important factor in the evolution of propelling gas is determined by the shape of the propellant grains. To illustrate this, consider again the spherically shaped propellant grains examined above. Since the gas evolves from the burning surface, at the start of burning large quantities of gas will be generated. As the charge burns, however, less and less gas will issue, since the area exposed to the burning process is reducing. This is termed degressive burning.

From similar considerations, the evolution of gas from the flat strip may be seen to be more or less constant, and this grain is said to have neutral burning characteristics. The web size here may be defined as the strip thickness.

At the start of combustion the perforated rod shaped grains burn from all surfaces, including the holes. In this case the area of propellant producing gas is increasing, at least until the holes are so enlarged, and the rod diameter so reduced as to leave slivers.

This grain geometry provides for the evolution of gas at rapidly accelerating rates.

To design a propelling charge for a lightweight shot, rapidly accelerating to reach extreme speeds down the gun bore, it becomes clear that the propelling grains should have the following characteristics:

1. The web thickness must be small, since the charge must reach it's "all burnt" condition before the shot exits the gun bore.

2. The shape of the grain must be of the progressive burn type, since the chamber volume will be increasing at a rapid rate as the shot gains speed.

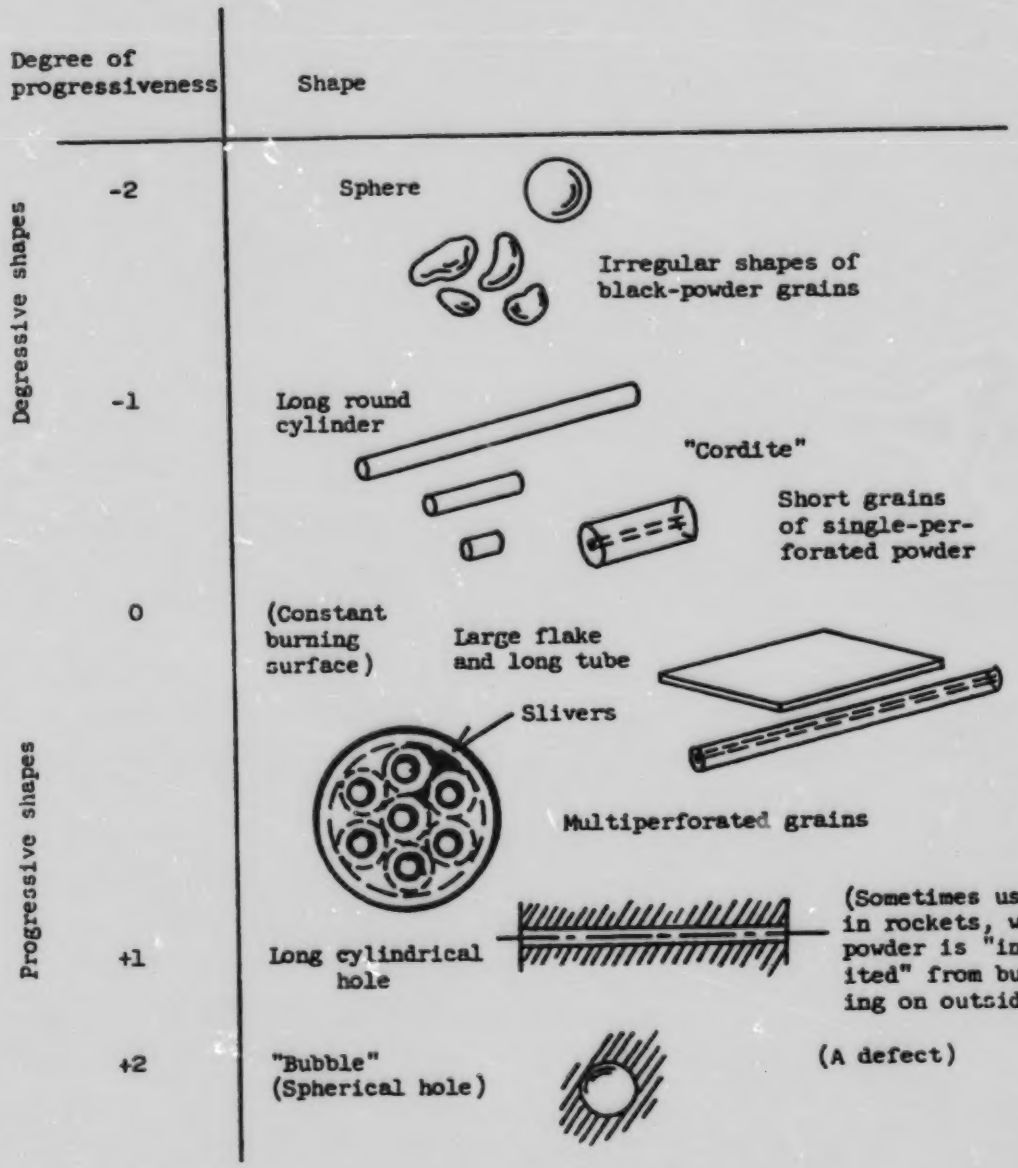
If the holes are equidistant from each other, and from the outer rod diameter, at the completion of burning only the small slivers remain; and the distance between the holes becomes the burn time governing dimension, (i.e. the web size). Sketches, drawn from Reference 9, and given as figure 4-1 illustrate these principles.

For any fixed gun and projectile combination, an optimum web size yielding maximum velocity exists. To amplify on this, should a too small web size be used, the pressures developed will quickly rise to the gun mechanical limit before the projectile has traveled much. The usable quantity of propellant is for this case limited by this pressure.

If on the other hand, a too thick web is employed, then the projectile will exit the gun bore before the propellant is completely burnt. In this case not all of the energy in the charge is liberated.

In a charge employing a web size optimized for maximum velocity, the pressures developed during the propellant burn process remain within the gun pressure containment capabilities, with the "all burnt" position lying near the muzzle.

Figure 4-1 Powder Grain Shapes



Progressiveness of powder grains.

5.0 Propellant formulation

At the outset of the charge design effort, a high performance propellant was sought. A double base composition, (nitrocellulose / nitroglycerine blend), such as propellant type M-8 or M-9 was considered suitable to attain the velocities desired. These propellant types were found not to be in widespread use, (they are used mainly for mortar charges), and were not available from D.N.D. stocks. Wider searches into U.S. stockpiles yielded similar results.

An investigation was carried out into the costs of manufacture of a small lot of propellant of optimized web. These costs were determined to lie within a range of $20 to $40 per pound for a minimum lot of 4000 lbs. This could not be accommodated in budgets then existing, and the search for supplies of propellant continued.

A quantity of type M-1 propellant was available from D.N.D. sources and this was examined for possible use. Some drawbacks to the possible employment of this propellant were considered, and these were:

1. The M-1 propellant was a "cool" operating type, (to minimize muzzle flash and to prolong gun barrel life), and the energy available on a per pound basis was considerably less than the M-8 type.

and

2. The propellant was pressed into grains, (i.e. optimized for another gun / projectile combination).

In Reference 5, Bull and Murphy give thermodynamic data for a limited number of propellants. A comparison of the M-1 and M-8 propellant types drawn from this reference is given in the table following.

Table 4-1 A Comparison of M-1 and M-8 Propellants

	M-1	M-8
Isochoric flame temperature, degrees K	2417	3695
Force constant, Ft - Lbs / lb	305,000	382,000
Density, Lbs. / cubic inch	0.0567	0.0585
Molecular Weight	22.1	27.0
Ratio of specific heats	1.2593	1.2148
Co-volume, cubic inches / lb.	30.57	26.63
Burning rate exponent	0.710	0.830

The flame temperatures provide one measure of the energy content of these propellants. While the M-1 at first glance, seems much less powerful than the M-8, it must be noted that very high velocities are intended; for this, the molecular weight comes into play. As the velocity of the shot increases, so also does the velocity of the gas pushing upon the projectile. A large fraction of the available energy is taken up in accelerating this gas.

In this we note that the lighter molecular weight of the M-1 offsets somewhat the temperature advantage of the M-8 propellant.

6.0 Interior ballistics studies

A series of computer simulations of propellant performance for the gun and the lightweight engine were carried out using the code of Reference 6. The objectives were fivefold, and are outlined below:

1. To evaluate the available M-1 propellant for suitability.
2. To compare performance differences between M-1 and M-8 propellants.
3. To develop a table of propellant charge weight vs. muzzle velocity.
4. To study the effects of shot start resistance on gun system performance.
5. To study the effects of weight variance of ignition composition on charge operation.

To carry out this investigation exact dimensions of the M-1 propellant grains were required, and for this a series of very satisfactory measurements were made by the hazardous materials group at D.R.E.S. These measurements are included in this report as appendix E.

The performance advantage of the M-8 composition was evaluated at 10 percent greater muzzle exit velocity, decreasing to half this value at the highest attainable speeds. With muzzle velocities approaching 6000 feet per second, a 10 percent increase would yield the highly desirable result of 6600 feet per second.

This comparison was made using a set of start conditions for a propelling charge of M-1 propellant; and repeating this run by substitution of the M-8 thermodynamic data into the start conditions. Although further performance gains would be likely, no attempt was made to optimize the M-8 grain geometry. The reasons for this was that the M-8 propellant would not likely become available, and the optimization procedure is quite lengthy.

A theoretical charge of type M-1 propellant, (as available), was created and put to simulated firings. The performance results were surprisingly satisfactory, and following upon this initial attempt, an extensive series of computer simulated firings was carried out. The results served as a basis for the detailed design of the propelling charge.

Not all of the factors affecting the performance of the charge could be computer simulated. Implicit in the computations is the assumption that the start of burning is simultaneous at all grain surfaces. Unfortunately this is not always true, as outlined earlier in section 2.0.

The design of the charge ignition system is directed to achieving simultaneous start of burning everywhere in the charge, and this work is described later in this report.

Other aspects in connection with computer modeling of the charge were the definition of the resistance of the shot during it's travel down the bore, the location of the shot start position, and consideration of the gun temperature at the time of firing.

For computational purposes, the shot start position was determined from the geometry of the gun and the test slug. The state of wear of the gun together with manufacturing tolerances, (of the driving band), will cause positional variations. The shot start position is important, since this determines the initial volume of the powder chamber. Down-bore shifts in shot start position are accompanied by decreases in launch velocity. One remedy for this is to add propellant to the charge.

The temperature of the gun is likewise important, since a cold barrel will absorb heat, (i.e. energy), from the propelling gas. This can sometimes be compensated for by firing a "warming" round immediately prior to a test series. It is difficult to apply this remedy here, since loading the engine / sabot into the gun will be a long process, and this will be followed by lengthy gas bag filling procedures. The entire loading and filling procedures can be anticipated to take several hours, by which time the warmed gun will have cooled down. Heating tapes, wound around the barrel may answer this.

The bore resistance function was attractive to consider since this was a parameter which could be modified during field trials, and which gave promise of increases in performance. The range of options available for this are as follows:

1. Reduce slightly, the outside diameter of the driving band, by machining.
2. Clean and lubricate the gun bore with suitable lubricant prior to loading.
3. Evacuate the gun bore prior to firing.

To evaluate the effect of such measures, a series of computational runs were carried out. These involved variations of the bore resistance function.

As a starting point, the resistance function for a standard 155 mm shell was employed, followed by reductions and increases to observe effects.

The principal result of these studies was to establish the operating pressures and the muzzle exit velocities of a series of charges; each increasing in weight using steps of one tenth of a pound. These results are given in graphical form in appendix F. The effects due to variations in bore resistance were then determined and likewise plotted.

The loss in performance due to high shot start resistance may be observed to be quite marked. The gains in muzzle velocity due to reductions in the shot start resistance are shown in the plotted results to be modest, but still of significance. For example, at the gun proof operating pressure the muzzle velocity is increased from 6430 feet per second, (1960 M / sec), to 6500 feet per second, (1981 M / sec). Thus the measures outlined may be just those necessary to reach the objective of 6560 feet per second, (2000 M / sec).

An important factor limiting launch performance is the gun mechanical pressure limit. Service guns are limited to 50,000 pounds per square inch operating pressure, due to torque loadings on the barrel key when firing heavy shells.

For the field trials here envisioned this limit will not apply, since the engine mass is only seven percent of mass of the standard projectile. The torque loads, (from the projectile accelerated to spin), are therefore reduced.

Important gains in performance are realizable by taking into account the gun operating pressure employed in proofing each barrel prior to entering service. This pressure level is 63,800 pounds per square inch, and the gun has been successfully fired at this pressure.

To launch the engine at 2000 meters per second, the studies indicate the following:

Table 6-1
Breech pressures at 2000 Meters / Second Muzzle Velocity

Ref. Run No.	Propellant Weight	Bore Resistance	Maximum Breech Pressure	Muzzle Velocity
45	35.22 Lbs.	"Low"	66,114 P.S.I.	2000 M / sec
1	35.22 Lbs.	"Std."	69,639 P.S.I.	2002 M / sec

7.0 Charge ignition considerations

An outline of the problems associated with ignition delays within the propelling charge were presented in section 2.0. In order to prevent high over pressures, a scheme along the lines of the multi-point, spaced charge arrangement used in the 16 inch H.A.R.P. guns was adopted. The operation of these charges is described by Bull and Murphy in Reference 5.

The principal features of the spaced charge arrangement are:

1. The use of an electrical circuit to overcome ignition timing delays,

and

2. The use of spacing devices to restrain the charge from movement during the initial stages of burning.

Consider the theoretical case of a charge ignited by means of a black powder primer running longitudinally down it's center. Let this charge measure 0.854 meters in length, which is the length of the powder chamber of the trials gun at hand.

Sassé, (Reference 7), in his work on black powder, gives flame spread rates of 2000 to 3000 meters per second in satisfactory operation under pressurized conditions. Taking into account the slower rates that obtain at the low pressures existing at start up, the time required to bring a flame front from the base of this charge to the forward end will be approximately 0.4 milliseconds.

If the base of the charge be covered with black powder, the flame front will advance from the center radially outward to the outer circumference in only 0.04 milliseconds. So the base end of the charge in this example, will be well into the gas evolution phase when the flame front has just reached the forward end of the charge.

To avoid this condition, an electrical ignition system has been devised and incorporated into the charge. Using electrical means to spread the ignition pulse throughout the charge, and to ignite the propellant simultaneously at a multiplicity of places, approximates the computer modeling assumption.

At ignition of the charge, we can expect that local gas generation rates within the charge will differ, giving rise to forces tending to accelerate the remaining solid propellant into motion.

To prevent this, a system of spacers between the charge elements is used. This serves to restrain the solid propellant from movement during the ignition start up period. Based on the considerations outlined above, the basic configuration of the charge for supersonic combustion trials comprises 10 separate bags of propellant. These are arranged in pairs, with each pair placed equidistant from adjacent pairs. The ends of this charge array are at the breech face and at the projectile base, leaving 4 spaces between the pairs of bags.

The charge is intended to be loaded manually, in sequence, bag by bag. Spacers inserted between bag-pairs serve to provide restraint to movement, and the assembled charge just fits into the powder chamber when the breech is closed.

The charge bags are cylindrical, with a length of approximately two thirds of the diameter.

The charges are initiated from one face of each cylindrical bag. Electrically fired squibs ignite a measured amount of black powder held in contact with each squib, in pockets sewn into the bag end closure.

The propellant grains immediately in contact with the black powder are easily ignited. Ignition is promoted by the grains of black powder, (which is also a propellant), and which fly about and become embedded in the body of the charge. Glowing red with heat, and embedded in the charge, the black powder then becomes a reliable ignition agent.

The bulk of the propellant, however, is ignited by hot gases generated by the black powder, and by hot gases evolved from the propellant proper, and for this it is desirable that the propellant bed be porous.

Propellant grains packed in random fashion present considerable resistance to gas flow, the propellant bed behaving also as a plug to flow within the powder chamber.

The impermeable nature of a randomly packed propellant bed gave rise to two charge design features. The first of these was to incorporate an orderly stacked propellant array into the design, to create porosity through the propellant bed. The principal function of this feature is to provide for early ignition of the propellant grains located at the interior of the bed. A second function is to assist the relief of pressure differentials between bags, arising out of differences in local gas generation rates.

An important characteristic of multi-point spaced charges is that charge operating pressures are reduced for a given weight of propellant. The corollary of this is that additional propellant can be employed when working to the gun pressure limit. The energy available for propulsion is thus increased. If, however, the ignition system fails in some respect, (e.g. a squib does not fire), the charge reverts to behavior normal for a charge of high loading density. That is to say, high overpressures develop.

In order to prevent these overpressures, a high degree of redundancy was designed into the ignition system.

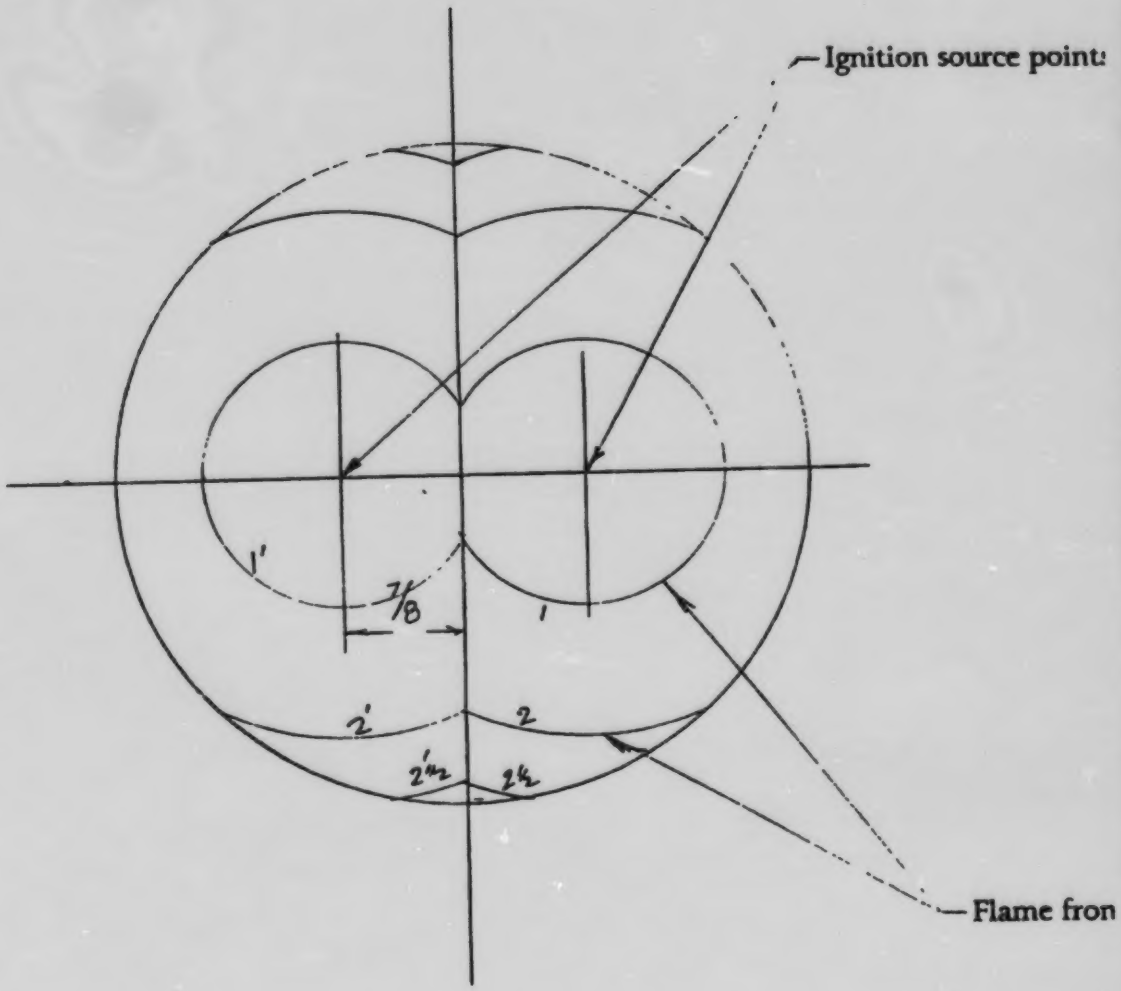
Each of the bags is equipped with a squib and a black powder filled pad. The squibs are wired in two separate circuits. The ignition end of each bag is placed adjacent to the ignition end of the next. In this way should one squib fail to operate, then the black powder pad that was supposed to be set off by the non functioning squib, will be set alight by the black powder pad facing and adjacent to it. So the failure to operate one individual squib, or the failure to operate half the complement of 5 squibs, does not prevent proper ignition of the charge.

The location of the squibs in the black powder ignition pad was a subject of study. Various start locations for flame spread within the black powder were examined, with the final configuration given as the diagram in figure 7-1. This illustrates two dimensional flame front travel in the black powder pad, originating from two separate sources. This design provides for the arrival of the flame front at the most distant parts of the charge in almost half the time needed for center located squibs. Proper orientation and spacing of the squibs in the black powder is controlled through loading procedures. These are described later.

The black powder ignition pads are offset from the centerline of the cylindrical propellant bags. This feature of the design is to provide for confined packing of the black powder. This offset condition is brought into symmetry through a procedure followed at the time of loading the charge into the gun.

Black powder burns slowly at atmospheric pressure, (about 1 cm. / sec.), but this rises rapidly under pressure to reach values of 2000 centimeters per second, or more. In the gun powder chamber, the space between propellant grains forms the initial volume into which the gas products of the black powder may flow, (and in so doing build up pressure). To accelerate this process the propellant bags are made from textiles which are less porous than the usual gauze like materials employed in charges featuring ignition sources exterior to the propellant bags. Since the black powder is located inside the propellant bag, this promotes a rapid initial rise in pressure, and the rate of burning is accelerated.

Figure 7-1 Results of a study for the location of igniter source points



The quantity of black powder employed to properly initiate propellant has been arranged at one eighty-fifth of the weight of the propellant contained in the bag. This ratio is based on the design of the H.A.R.P. 16 inch multi-point spaced charges. Provision to change the quantity and the distribution of the black powder is incorporated into the design of the sewn pockets of the ignition pads.

An internal ballistic study was carried out to observe the effect of additions to the black powder igniters. The results, tabulated below, show that the principal effect is to raise the operating pressure, but without a corresponding increase in launch velocity.

Table 7-1 Black Powder Sensitivity Study

Black powder igniter weight Lbs.	Propellant weight Lbs.	Ratio of Propellant weight to Igniter weight	Maximum Pressure P.S.I.	Launch Velocity Ft. / Sec.
0.365	34.0	93 : 1	63,452	6409
0.730	34.0	46 : 1	64,151	6410
1.095	34.0	31 : 1	64,840	6411

8.0 Data for charge system components

A list of charge design features is drawn up and presented below:

1. The propellant is packed into 10 separate bags.
2. The bags are placed into the gun powder chamber in pairs.
3. The bag pairs are held in position by spacers, preventing movement within the powder chamber.
4. The propellant within the bags is packed in an orderly, stacked array to create porosity, and to provide for gas flow through the propellant bed.
5. Each bag is provided with ignition means.
6. Ignition of the charge is made simultaneous at all bags through electrically fired squibs.
7. The means of ignition at each bag is located at one end of the bag.
8. The electrically fired squib ignites a measured quantity of black powder held in a series of sewn pockets, forming an ignition pad.
9. In the gun, the ignition pads of each bag are adjacent, and are in contact to develop pyrotechnic redundancy.
10. To provide for electrical redundancy, the firing circuit is divided into two parts, each firing a set of five squibs.
11. Squibs are offset from the charge centerline, to reduce the flame front travel distance to the extremities of the ignition pad.
12. The diameter of the propellant bags is smaller than the diameter of the gun powder chamber. This creates ullage space, and provides a gas flow channel to equalize pressures throughout the charge.

The general arrangement of the charge is given in figure 8-1.

Figure 8-1 Charge General Arrangement

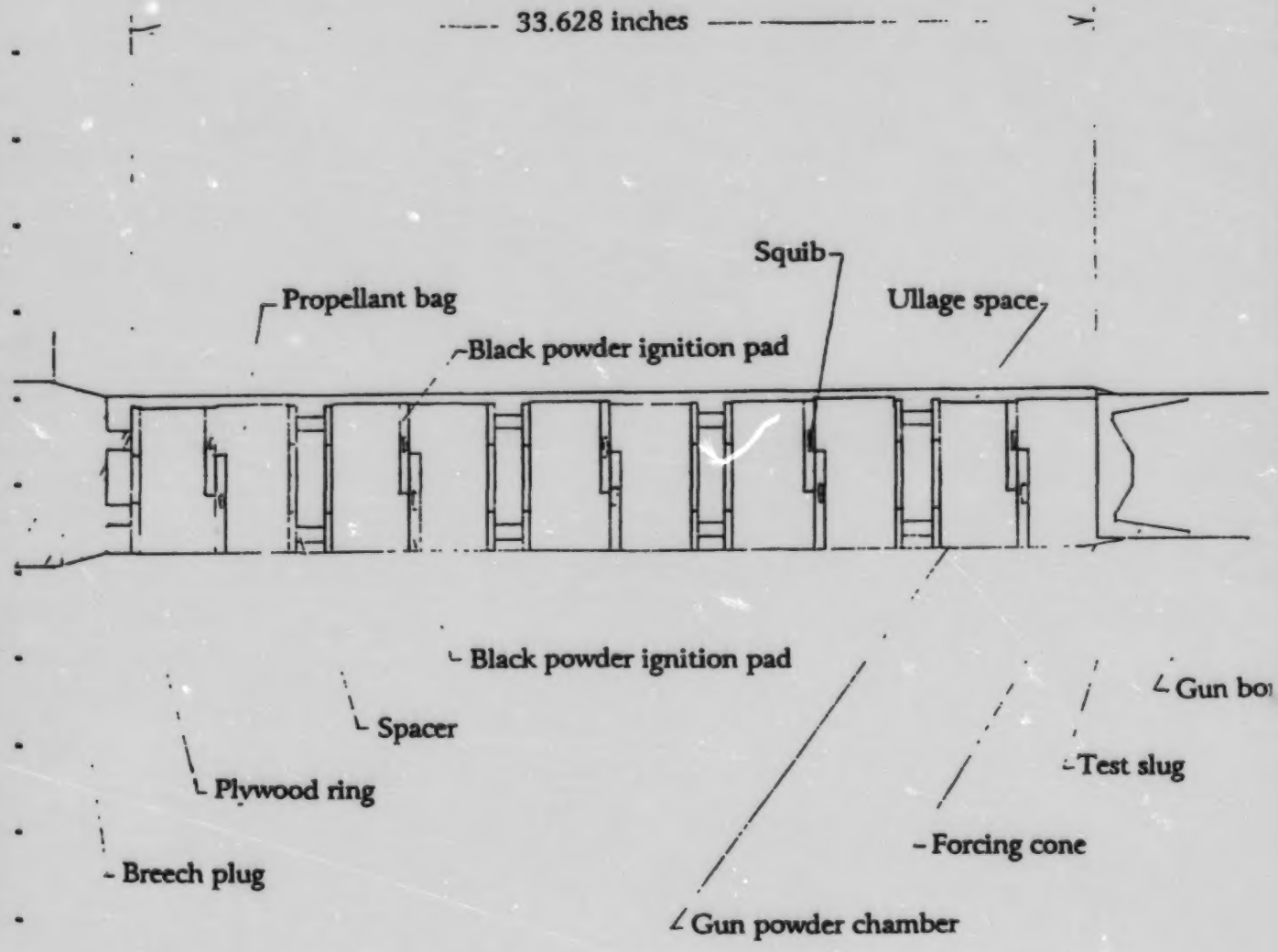


Table 8-1 Black Powder Data *

U.S. Manufacture, Grade A-2, for cannon.

U.S. Standard sieve size: 5 to 10

Isochoric flame temperature: 2180 degrees K

Impetus: 97,020 Ft. - Lbs. / Lb.

Co - Volume: 21.73 cubic inches / Lb.

Gamma: 1.2184

Molecular weight of the gas: 33.654

* From Reference 8

Table 8-2 M-1 Propellant Data *

Propellant composition:	Type M-1
Isochoric flame temperature:	2449 degrees K
Burning rate exponent:	0.710
Burn rate coefficient:	2.5 x 10
Propellant density:	0.0567 Lbs. / Sq. In.
Co - Volume:	30.62 cubic inches / Lb..
Impetus:	307,853 Ft-Lbs. / Lb.
Ratio of specific heats:	1.2674
Propellant grain diameter:	0.145 inches **
Propellant grain length:	0.315 inches **
Number of perforations:	7
Propellant web thickness:	0.0265 inches
Diameter of perforation:	0.013 inches **

* From Reference 5 and Reference 8
** Values obtained through measurement

Pyrotechnic Squib Data

C-I-L Model S-140 Squib

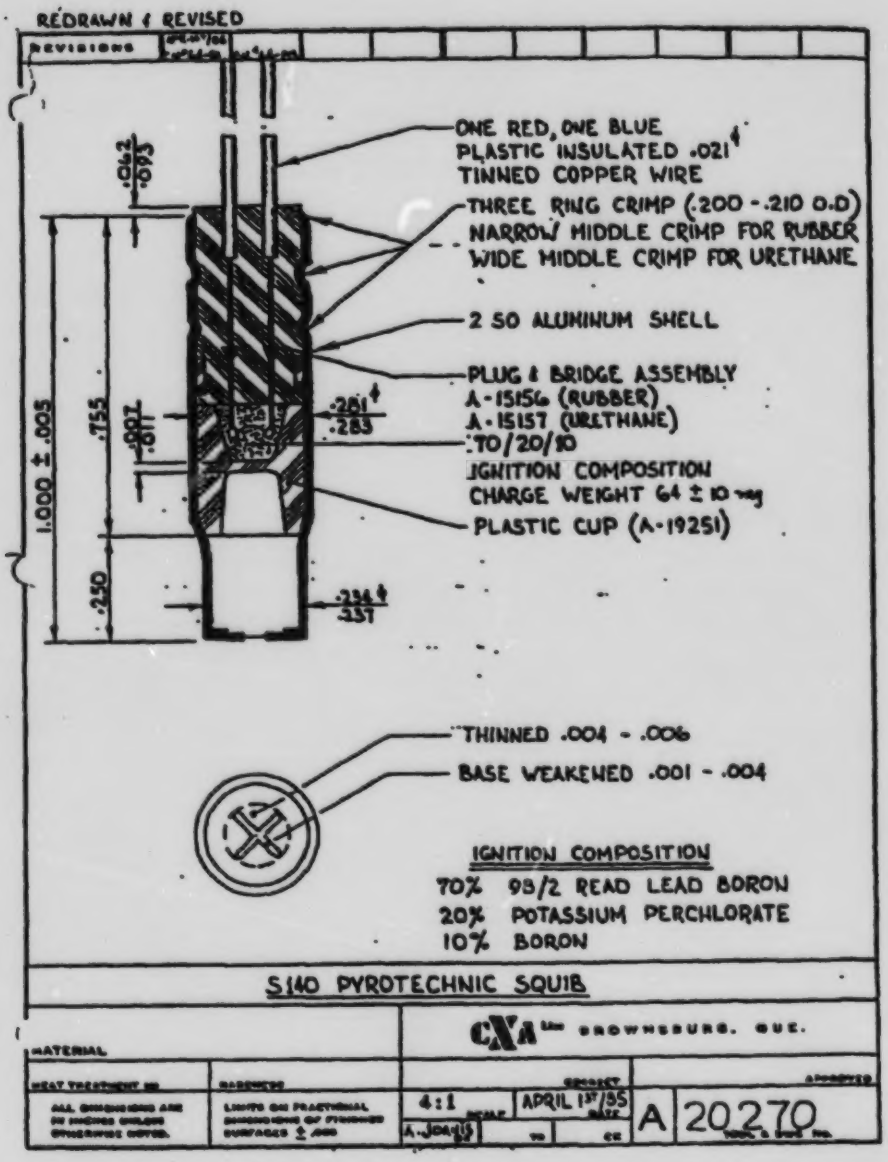
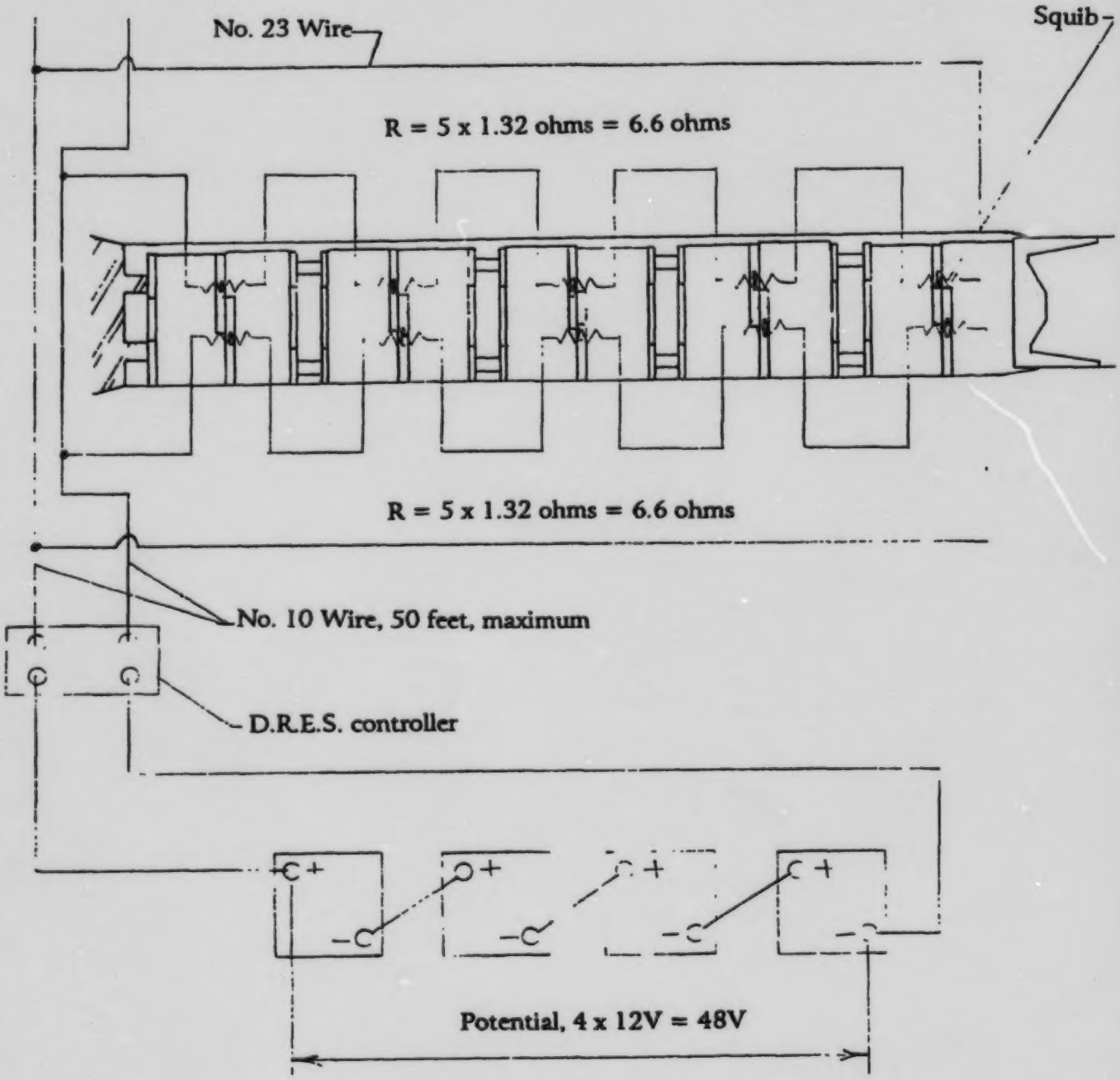


Figure 8-2 Squib Firing Circuit



Squib Electrical Firing Current

Potential source: 4 batteries in series, Automotive lead acid type, 12 volts each, 48 volts total

Squib circuit resistance, loop 1: 5 squibs x 1.32 ohms each = 6.6 ohms
Squib circuit resistance, loop 2: 5 squibs x 1.32 ohms each = 6.6 ohms

Resistance of lead wires: 50 feet x 2 = 100 feet total lead wire length
Resistance of No. 10 wire = .9991 ohms per 1000 feet
Resistance of lead wires = 100 / 1000 x .9991 = 0.099 ohms

Total resistance of squib circuit = Resistance of leads + Resistance of squibs
= 0.099 ohms + 6.6 ohms / 2 = 3.34 ohms

Current at firing: I = E / R = 48 volts / 3.34 ohms = 14.37 amperes

Current in each squib loop = 14.37 amperes / 2 = 7.18 amperes

Current limit for No. 23 wire: 7 amperes*

Current limit for No. 10 wire: 250 amperes*

Squib time to function: 0.2 milliseconds*

Minimum current to minimize squib operating time: 5 amperes*

* From Reference 11

Gun Data

The gun is comprised of two principal elements:

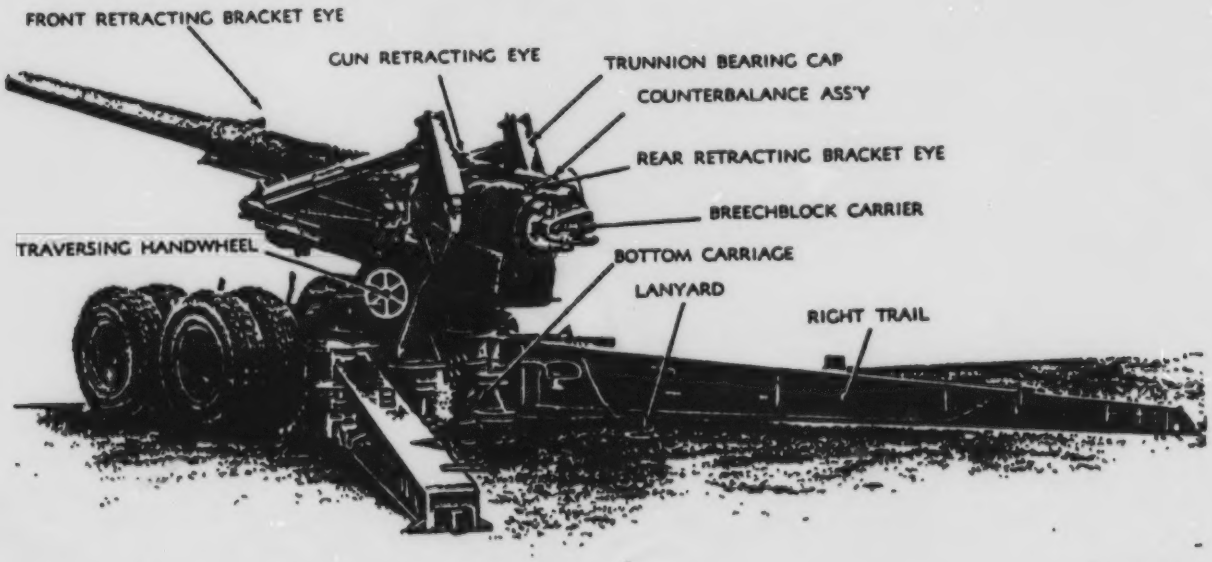
1. A rifled 155 mm barrel, model M-185

and

2. A "Long Tom" mount*

*The mount is modified to accept this barrel.

Figure 8-2 Long Tom Gun Mount*



155-mm Gun in Firing Position — Left Rear View

*From Reference 10

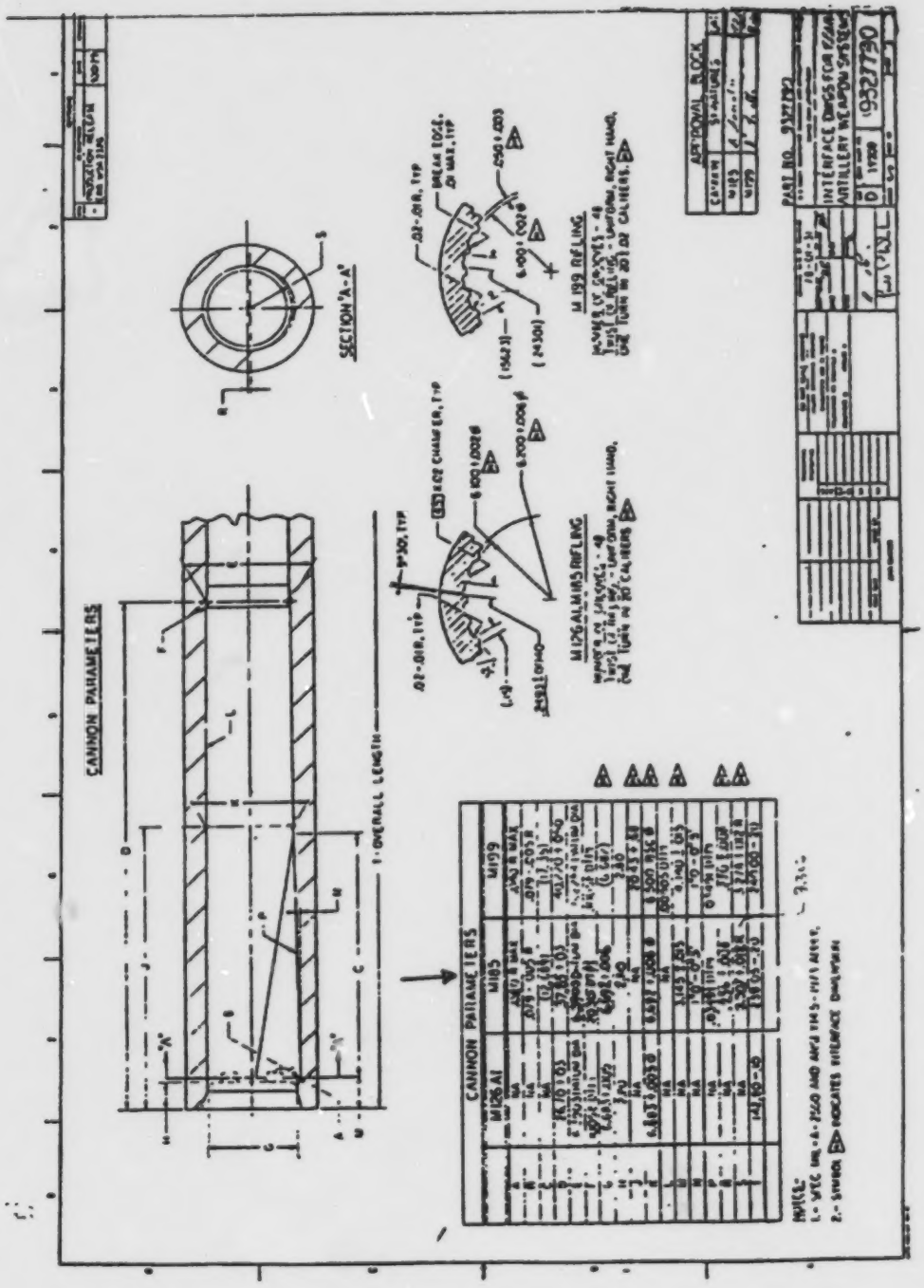
Data for M-185 barrel

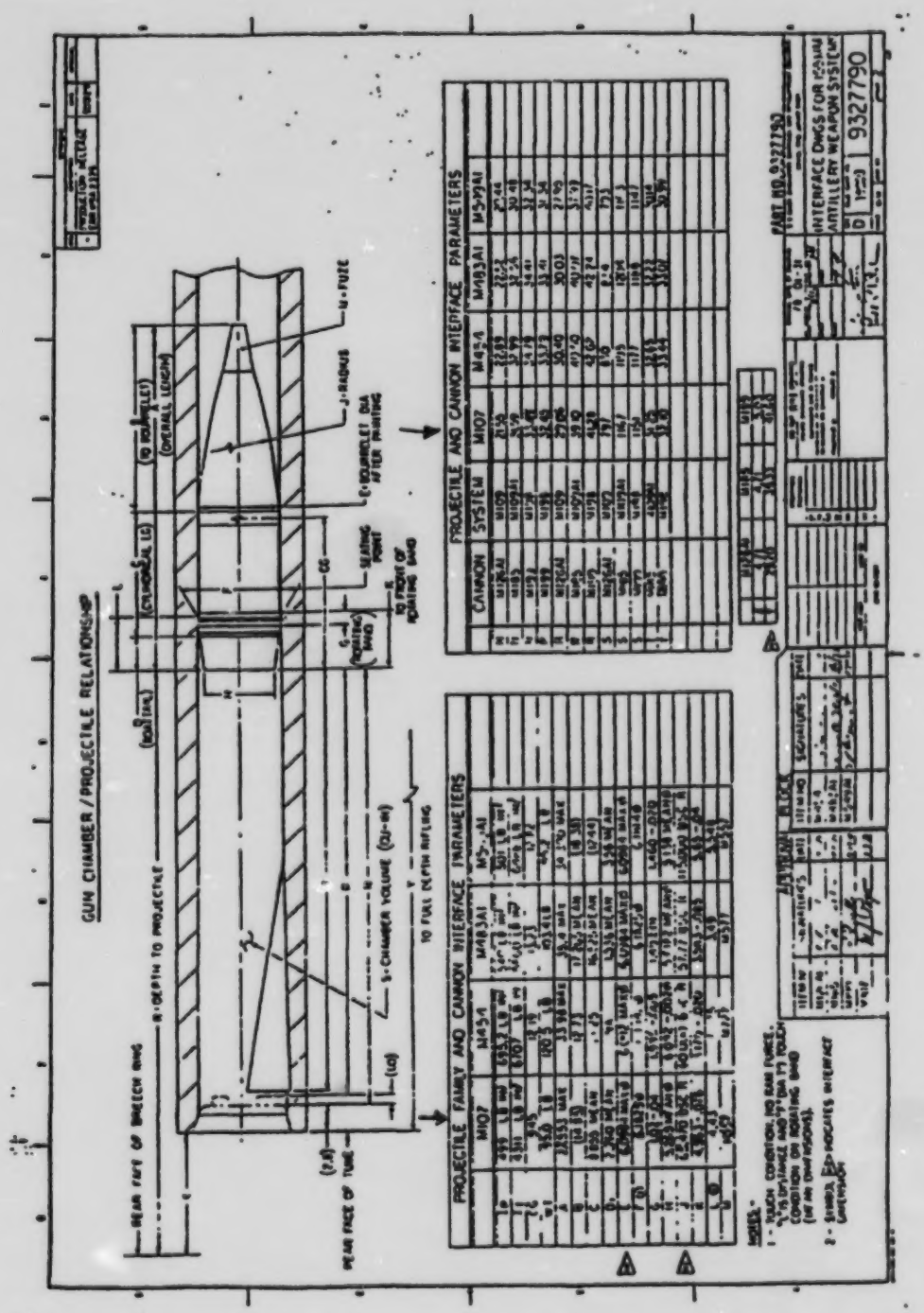
Powder chamber volume = 1186.61 cubic inches

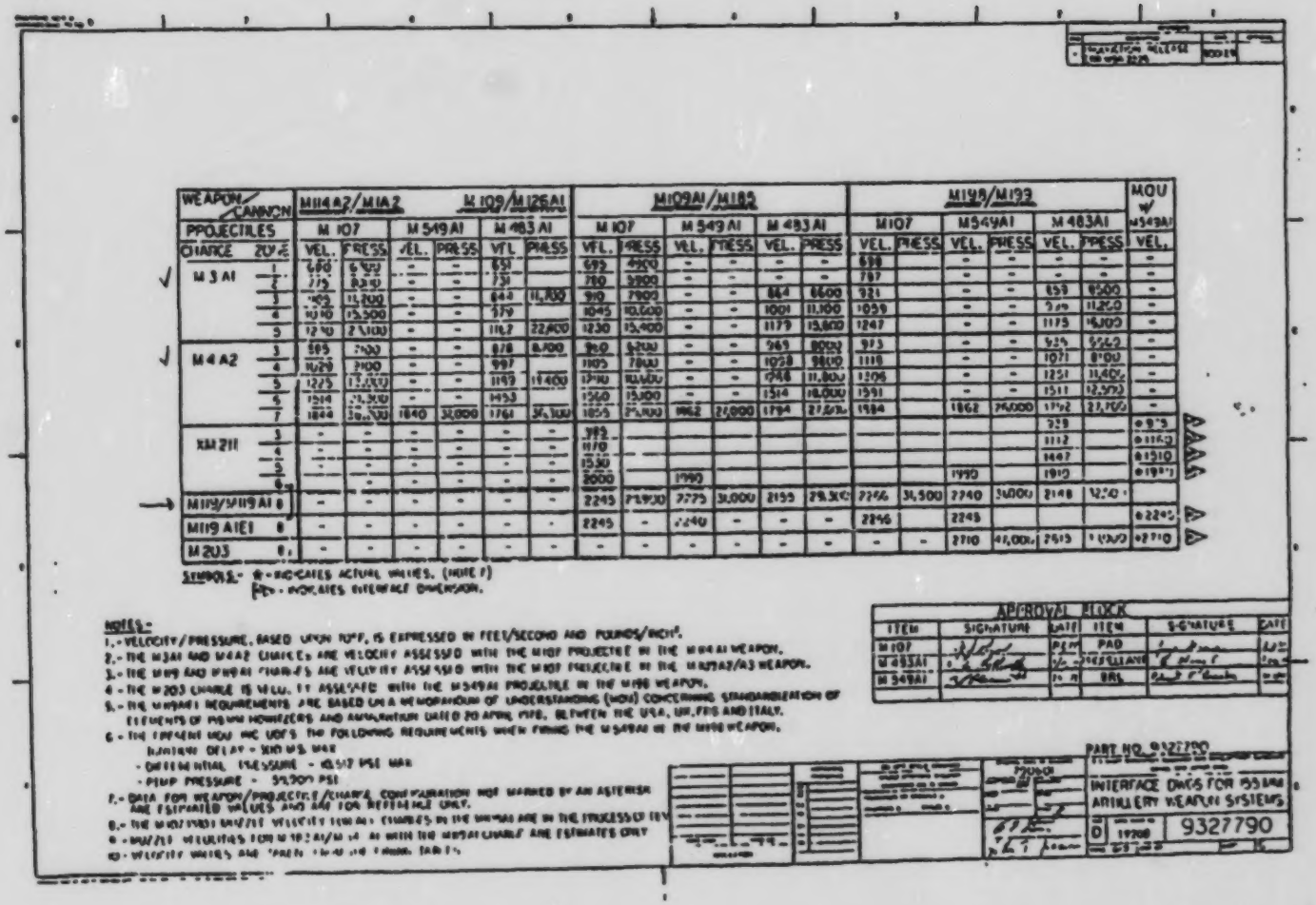
Calculated for a gun in new condition,
with seated test slug.

Shot travel = 199.81 inches

Dimensions, Projectile Loading, and Performance Information for Standard Rounds is given on the following three pages.


CANNON PARAMETERS
SECTION 'A-A'
M199 RIFLING
M126A1/M185 RIFLING
OVERALL LENGTH
CANNON PARAMETERS
M126A1
M185
M199
NOTES:
1.- SEE DWG. A-2220 AND DWG. A-2221
2.- SYMBOL INDICATES INTERFACE DIMENSION
PART NO. 9327190
INTERFACE DRAWING FOR 155MM ARTILLERY WEAPON SYSTEM
9327190


GUN CHAMBER / PROJECTILE RELATIONSHIP
PROJECTILE AND CANNON INTERFACE PARAMETERS
PROJECTILE FAMILY AND CANNON INTERFACE PARAMETERS
INTERFACE DWGS FOR 120MM ANTITANK WEAPON SYSTEM
9327790



WEAPON / CANNON	M114A2/M1A2				M109/M126A1		M109A1/M185						M198/M193						MOU W M549A1
PROJECTILES	M107		M549A1		M483A1		M107		M549A1		M483A1		M107		M549A1		M483A1		
CHARGE	ZONE	VEL.	PRESS	VEL.	PRESS	VEL.	PRESS	VEL.	PRESS	VEL.	PRESS	VEL.	PRESS	VEL.	PRESS	VEL.	PRESS	VEL.	PRESS	VEL.
M3A1	1	680	6,900	-	-	651		692	4900	-	-	-	-	538		-	-	-	-	-
	2	775	8,200	-	-	731		780	5900	-	-	-	-	787		-	-	-	-	-
	3	1003	11,200	-	-	844	11,300	910	7900	-	-	864	8600	931		-	-	858	8500	-
	4	1190	13,500	-	-	979		1045	10,600	-	-	1001	11,100	1059		-	-	979	11,200	-
	5	1290	15,100	-	-	1062	22,400	1230	15,400	-	-	1179	15,800	1247		-	-	1175	15,100	-
M4A2	3	585	7,100	-	-	878	8,100	910	6200	-	-	969	8000	973		-	-	924	9260	-
	4	1029	9400	-	-	997		1105	7800	-	-	1058	9800	1118		-	-	1071	8900	-
	5	1225	12,200	-	-	1193	19,400	1310	10,400	-	-	1248	11,800	1206		-	-	1251	11,400	-
	6	1394	14,300	-	-	1358		1360	13,100	-	-	1514	14,800	1391		-	-	1511	12,973	-
	7	1844	26,700	1840	31,000	1761	31,300	1855	23,900	1862	27,000	1794	27,600	1984		1862	24,000	1792	23,700	-
XM211	3	-	-	-	-	-	-	992										928		0 875
	4	-	-	-	-	-	-	1170										1112		0 1156
	5	-	-	-	-	-	-	1330										1407		0 1510
	6	-	-	-	-	-	-	2000		1990						1990		1910		0 1971
M119/M119A1	8	-	-	-	-	-	-	2245	23930	2225	31,000	2155	29,300	2246	31,500	2240	31,000	2148	27,200	
M119A1E1	8	-	-	-	-	-	-	2245	-	2240	-	-	-	2246		2245				0 2245
M203	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2710	41,000	2615	37,500	0 2710

SYMBOLS:- ✱ - INDICATES ACTUAL VALUES. (NOTE 1)
[ ] - INDICATES INTERFACE DIMENSION.

NOTES:-
1.- VELOCITY/PRESSURE, BASED UPON PUFF, IS EXPRESSED IN FEET/SECOND AND POUNDS/INCH².
2.- THE M3A1 AND M4A2 CHARGES ARE VELOCITY ASSESSED WITH THE M107 PROJECTILE IN THE M114A2/A1 WEAPON.
3.- THE M198 AND M109A1 FIGURES ARE VELOCITY ASSESSED WITH THE M107 PROJECTILE IN THE M114A2/A1 WEAPON.
4.- THE M203 CHARGE IS M.U.U. IT ASSESSED WITH THE M549A1 PROJECTILE IN THE M198 WEAPON.
5.- THE M198A1 REQUIREMENTS ARE BASED ON A MEMORANDUM OF UNDERSTANDING (MOU) CONCERNING STANDARDIZATION OF ELEMENTS OF HOWITZERS AND AMMUNITION DATED 20 APRIL 1978, BETWEEN THE USA, UK, FRG AND ITALY.
6.- THE DIFFERENT MOU MC USES THE FOLLOWING REQUIREMENTS WHEN FIRING THE M549A1 IN THE M198 WEAPON.
- IGNITION DELAY - SEE MIL SPEC
- DIFFERENTIAL PRESSURE - 45,517 PSI MAX
- PUMP PRESSURE - 51,700 PSI
7.- DATA FOR WEAPON/PROJECTILE/CHARGE CONFIGURATION NOT MARKED BY AN ASTERISK ARE ESTIMATED VALUES AND ARE FOR REFERENCE ONLY.
8.- THE M107/M483 AND/OR M549A1 CHARGES IN THE M198 ARE IN THE PRESSURED FIRING MODE.
9.- M119/A1 FIGURES FOR M102A1/M14 AS WITH THE M109A1 CHARGE ARE ESTIMATES ONLY
10.- VELOCITY VALUES ARE TAKEN FROM FIRING TABLES

APPROVAL BLOCK					
ITEM	SIGNATURE	DATE	ITEM	SIGNATURE	DATE
M107			PEM	PAO	
M483A1			PM	SARCOM	
M549A1			PM	BRL	

PART NO. 9327790

INTERFACE DATA FOR 155mm ARTILLERY WEAPON SYSTEMS

D | 19208 | 9327790

Propellant packing data

In determining propellant bag dimensions, it was necessary to find a suitable packing geometry. The hazardous materials group at D.R.E.S. undertook to measure propellant packed in both random fashion, and in stacked array. For these measurements the M-1 propellant was packed into especially prepared aluminum canisters, approximating the candidate bag size, and of extremely lightweight construction. The weight of the containers constituted about one tenth of the weight when filled, this to promote measurement accuracy.

This series of measurements yielded highly satisfactory results, and these are outlined below:

Stacked propellant, apparent density: 0.0421 Lbs. / Sq. inch

Random packed propellant, apparent density: 0.0317 Lbs. / Sq. inch

Capacity of the gun powder chamber:

a. When completely filled with propellant in stacked array = 49.98 Lbs.

b. When completely filled with randomly packed propellant = 37.72 Lbs.

Packing ratio, Stacked / Random: 0.0421 / 0.0317 = 1.32

The packing measurement observation data is included in appendix E. The filled canisters of propellant at measurement, are shown in the photographs given as figure 8-3 and 8-4.

Figure 8-3 Random packed propellant grains

D.R.E.S. Photo 9802819

Figure 8-4 Propellant grains in stacked array

D.R.E.S. Photo 9802802 - The light reflected from the spaces between the stacked grains illustrates the porous nature of the packing scheme.

The propellant bag design diameter was fixed at 6.312 inches. The powder chamber diameter is 6.692 inches. The difference in these diameters creates a crescent shaped space between the bag and the powder chamber wall. The width of this space is 0.38 inches at it's maximum point. This is a rather large space, but it is needed for the relief of gas pressure differences arising from variations in local gas evolution rates.

Part 2 Filling Procedures

9.0 Filling ignition pad assemblies

The ignition assembly consists of a set of five pockets sewn onto a circular cloth element, which forms the top closure of each bag of propellant. The pockets are shown in the photograph given as figure 9-1.

The circular cloth element is bonded to a thin plywood ring and is provided with five short slots giving access to the pockets. The ring provides stiffness, maintains the circular bag geometry when assembled, and presents a firm seat for bags adjacent. The slot and ring detail is illustrated in figure 9-2.

A flap covers the slots when filling operations are completed.

Black powder is introduced into the each pocket through the slots in the following way:

1. 4.4 grams into each of the four outer pockets.
2. 1.5 grams is then placed into the center pocket.
3. Next, one squib is placed into the center pocket, with the wires left trailing at the outside of the pocket.
4. Finally 1.0 grams of black powder is placed into the center pocket on top of the squib, and alongside the wires.
5. After these filling operations have been completed, the flap is bonded down over the slotted area.
6. The filled ignition assembly is then set aside to allow the adhesive to cure.

7. Fabric cement is employed to bond the flap.

8. The tools and supplies shown in figure 9-3 are useful in accomplishing the tasks outlined above.

The finished ignition pad is shown in the photographs given as figure 9-4 and 9-5.

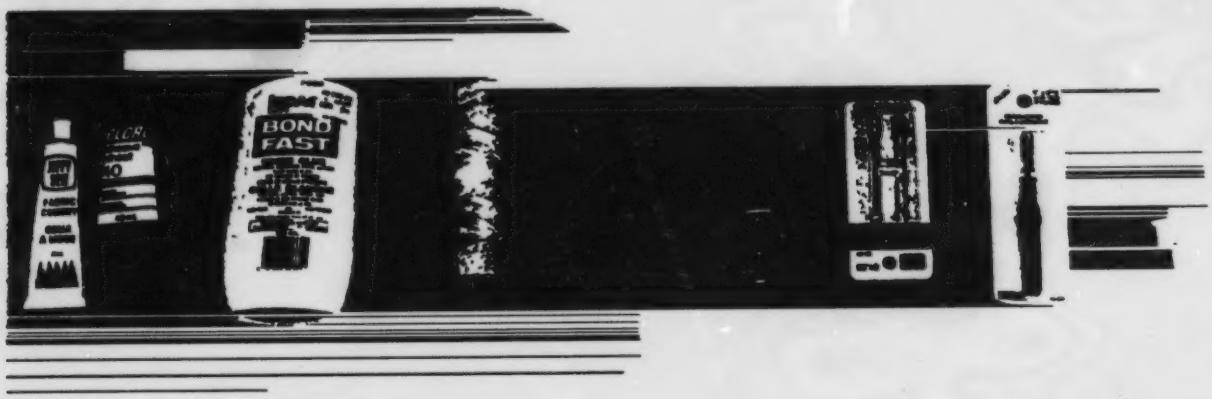
Figure 9-1 Ignition pockets

D.R.E.S. Photo 9806918

Figure 9-2 Ignition pad assembly, view of exterior details

D.R.E.S. Photo 9806916

Figure 9-3 Tools and supplies for bag filling operations



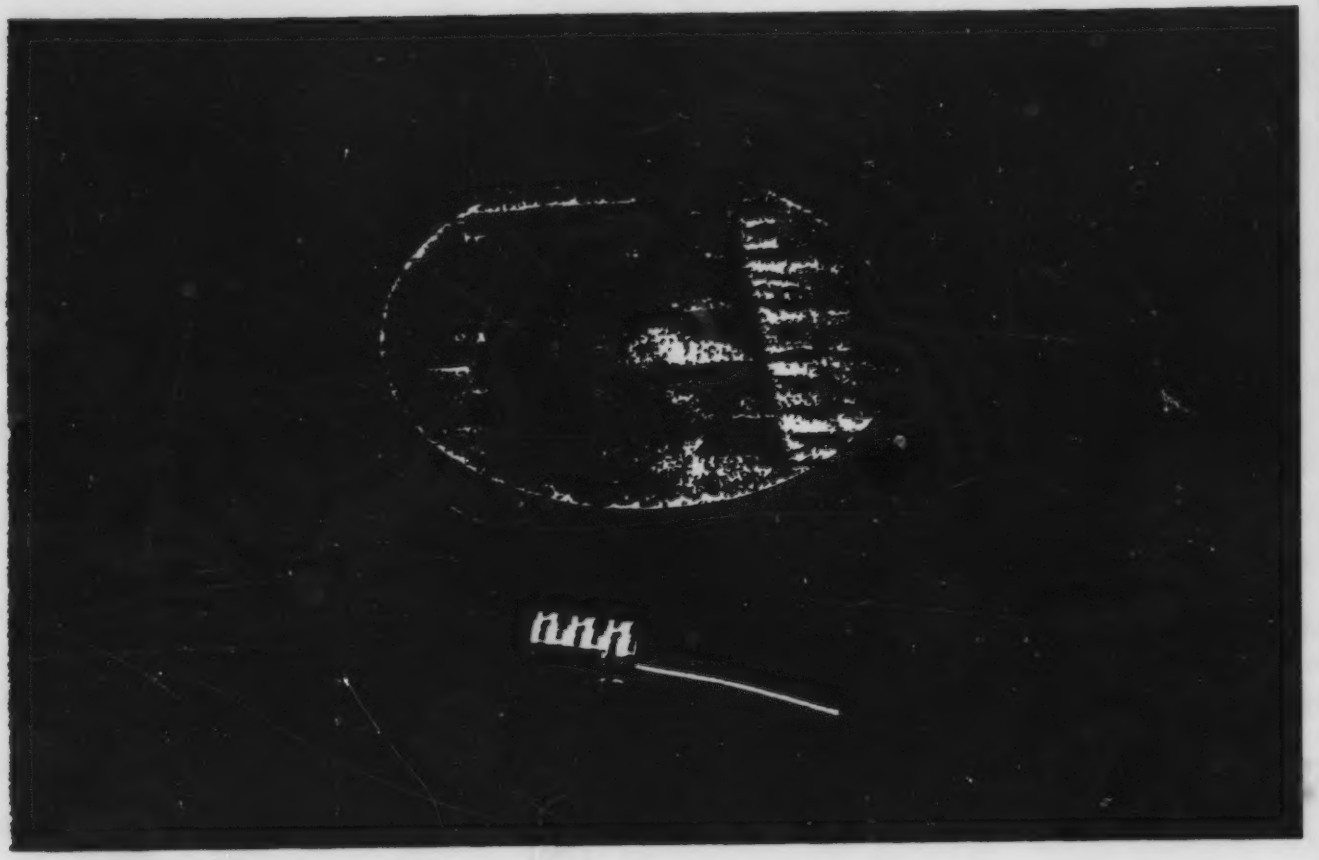
D.R.E.S. Photo 9806929

Key to items shown in the photograph given as figure 9-3
Tools and Supplies for bag filling operations

The items detailed below are given in order from left to right

Item 1	Fabric cement, "Jiffy sew", used to bond flap over ignition filling slots.
Item 2	Fabric cement, "Velcro adhesive", used to bond flap over ignition filling slots.
Item 3	Water based wood glue, "Lepage bond fast", used to bond ignition unit into bag to form permanent closure.
Item 4	Cord, used to make up drawstring to close propellant bag.
Item 5	Slender wooden dowels, used to prod black powder into pockets.
Item 6	Marker.
Item 7	Threading tool, used to thread drawstring through bag closure loops.
Item 8	Seam ripping tool, used to enlarge ignition pocket size.
Item 9	Funnel, used to feed black powder through slots into pockets.

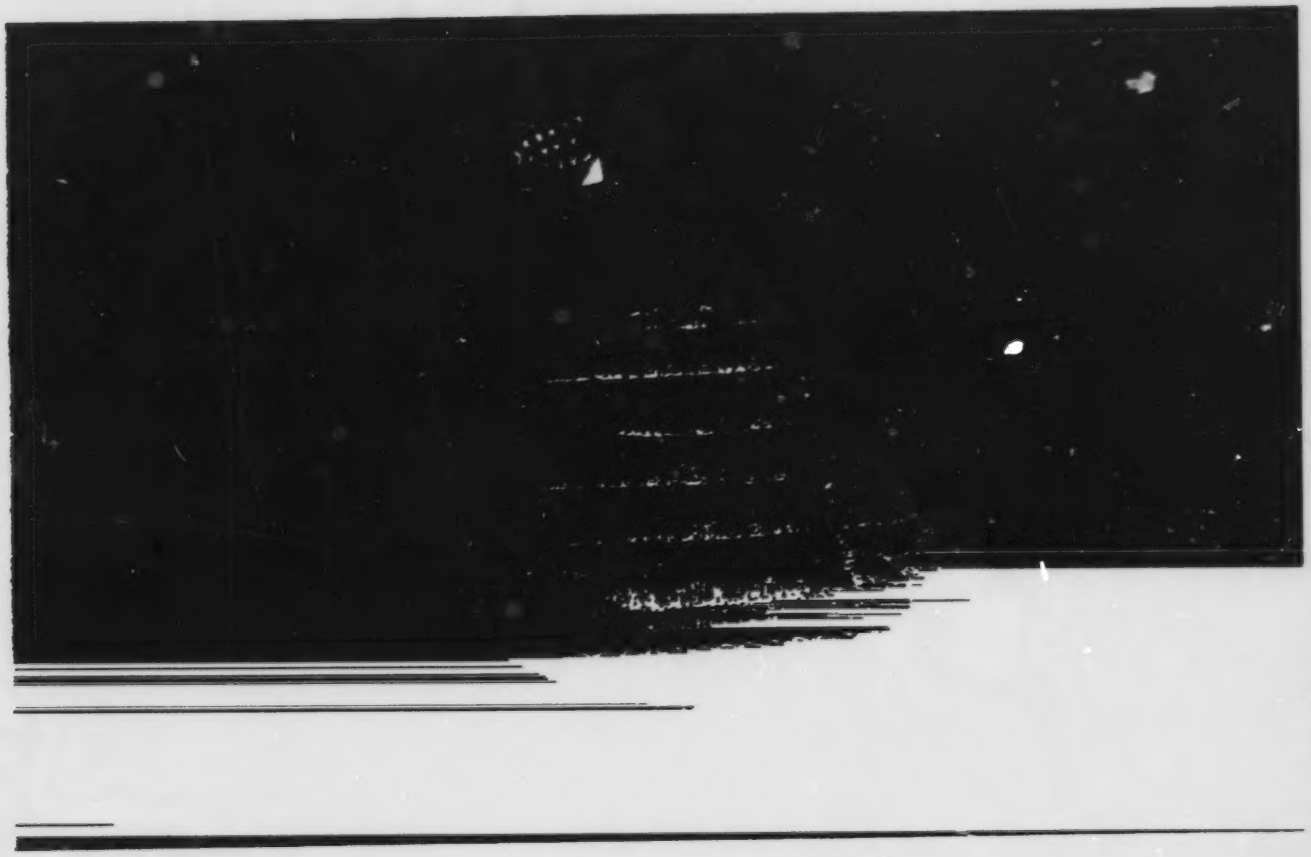
Figure 9-4 Ignition pad. exterior view showing sealed flap and squib lead wires



D.R.E.S. Photo 9806915

Figure 9-5 Ignition pad, view of interior surface.

The pockets contain black powder.
Enlargement of one or more pockets may be accomplished
by ripping the right hand seams.



D.R.E.S. Photo 9806914

10.0 Filling bags with propellant

The propellant bags consist of a fabric sleeve bonded to a circular cloth covered ring. The ring is of thin plywood and in the radial direction, is quite stiff. This ring forms the flat bottom of the propellant bag which is held circular by the ring.

The ring also serves as a means of support of the propellant packed into the bag, the support being required to prevent longitudinal movement of the charge. These design features may be observed by referring to the photograph given as figure 10-1.

A series of loops are incorporated into the top of the sleeve, and these accommodate a drawstring which serves to hold the bag closed after filling.

The bags are arranged into three different lengths, to accommodate three propellant packing heights. The propellant is packed in layers, and these number 7 layers, 8 layers, and 9 layers. These three sizes of charge increment, when combined in various combinations, (totaling up to ten increments), provide a means of adjusting and controlling gun performance.

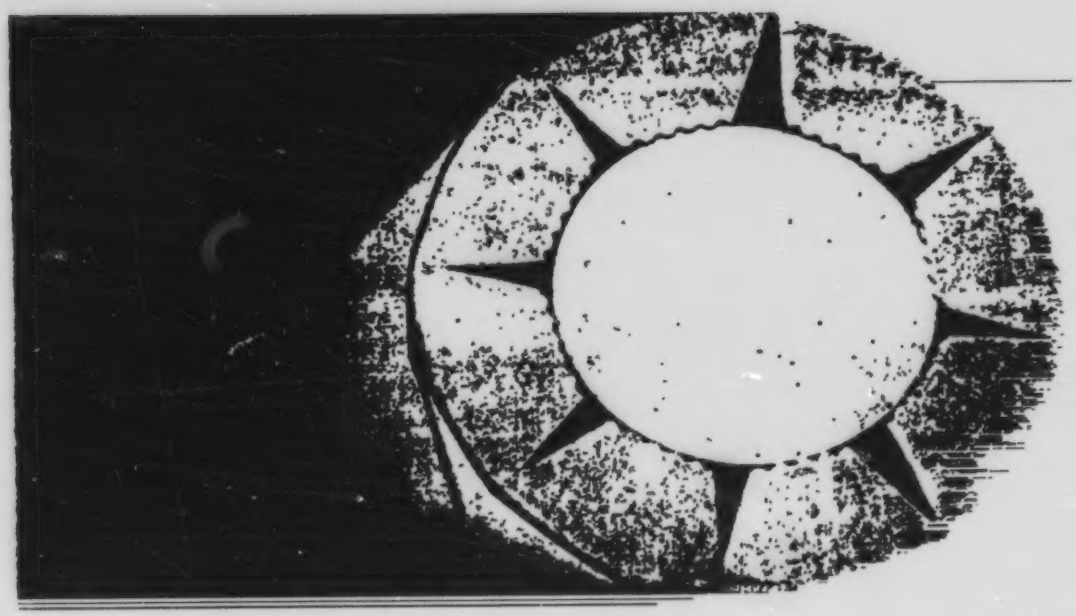
The number of layers of propellant to be packed into a particular bag is marked on the bag. So bags are marked with the numeral "7", "8", or "9". A view of a bag, empty, and ready for packing with propellant is shown in the photograph given as figure 10-2.

When filling bags it will be found convenient to mount them in the support ring shown in figure 10-3. The bags are held securely in place within the support ring using masking tape. Bag entry into the support ring and the method of securing it with tape is illustrated in the two photographs given as figure 10-4 and 10-5.

The filling of the bag with propellant is done manually, and it is a lengthy process. The reader may note that the stacking process could be automated, however this is economical only when production in volume is required.

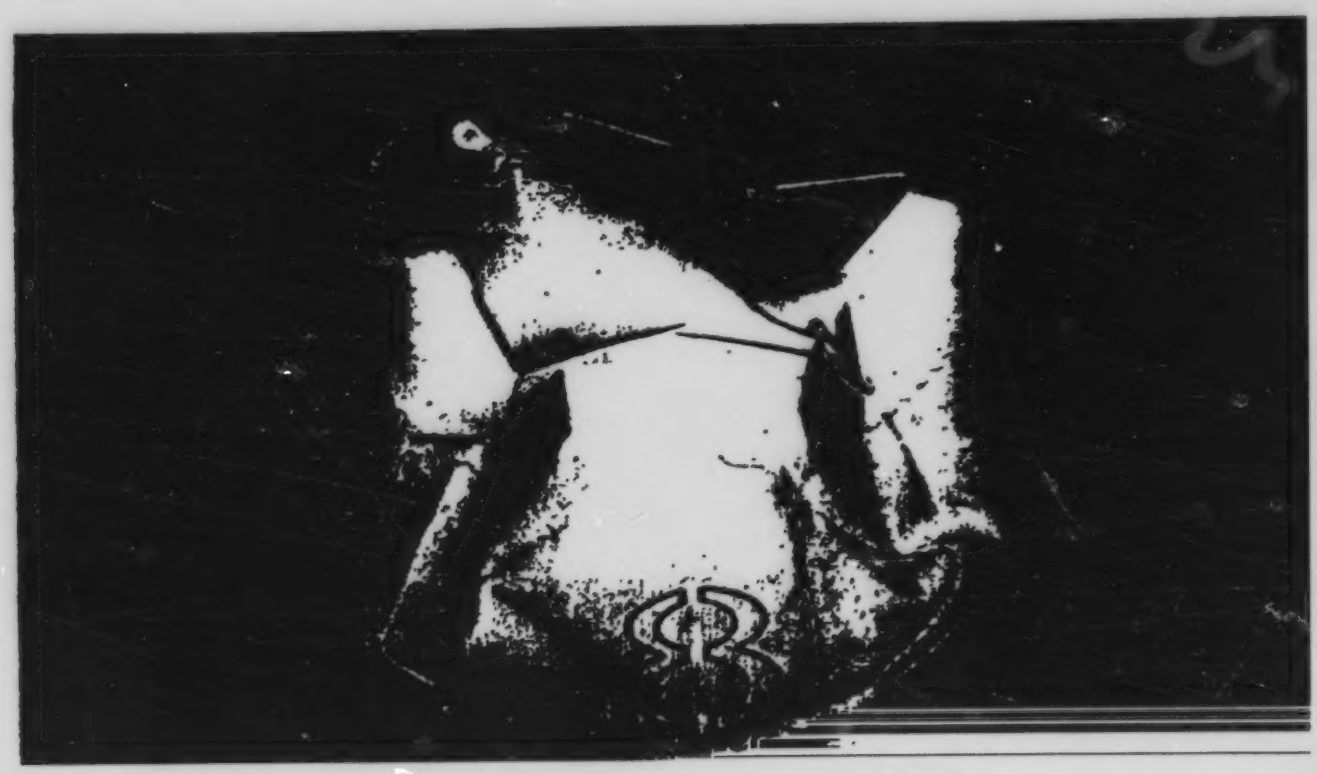
To control the lie of individual propellant grains, and to prevent shifting of the grains during stacking, the bag support ring is mounted at a 30 degree angle from the horizontal.

Figure 10-1 Propellant bag, exterior view, bottom



D.R.E.S. Photo 9806922

Figure 10-2 Propellant bag, exterior view



D.R.E.S. Photo 9806921

Figure 10-3 Filling support ring

D.R.E.S. Photo 9806920

Figure 10-4 Bag placement into support ring

D.R.E.S. Photo 9806919

Figure 10-5 View of filled propellant bag

D.R.E.S. Photo 9806910

With a suitable pair of large tweezers, propellant grains may be handled two at a time.

One layer of stacked propellant consists of 1691 grains. When stacked in orderly fashion, with each grain in contact with the other adjacent, a circle of 6.312 inches in diameter is formed.

When packing to form an assembled charge it is not necessary to count grains. Since the weight of one layer is 185.395 grams, to obtain propellant sufficient to pack one layer, all that is needed is to weigh out 185.395 grams.

We recommend to work as a team of five workers.

One will weigh out propellant, close bags, and set up bags for filling.

The four others would pack as two teams of two workers each. To divide the packing task, the first packer would stack to a level of approximately 80 percent of one layer. The second packer would complete the last 20 percent. The first 80 percent is simpler to accomplish than the remainder.

During the final 20 percent, exact placement of grains is required. The grains tend to fall out of position near the circumference of the circle. One method that has produced good results is to work outwards from the vertical centerline.

A filled bag is shown in the photograph given as figure 10-6.

Figure 10-6 A filled charge bag showing stacked propellant array

D.R.E.S. Photo 9806912

After filling the bag with an appropriate number of layers, the securing tapes at the top end of the bag are removed.

A draw string is cut to length and threaded through the loops at the bag top end using the threading tool shown in figure 9-3.

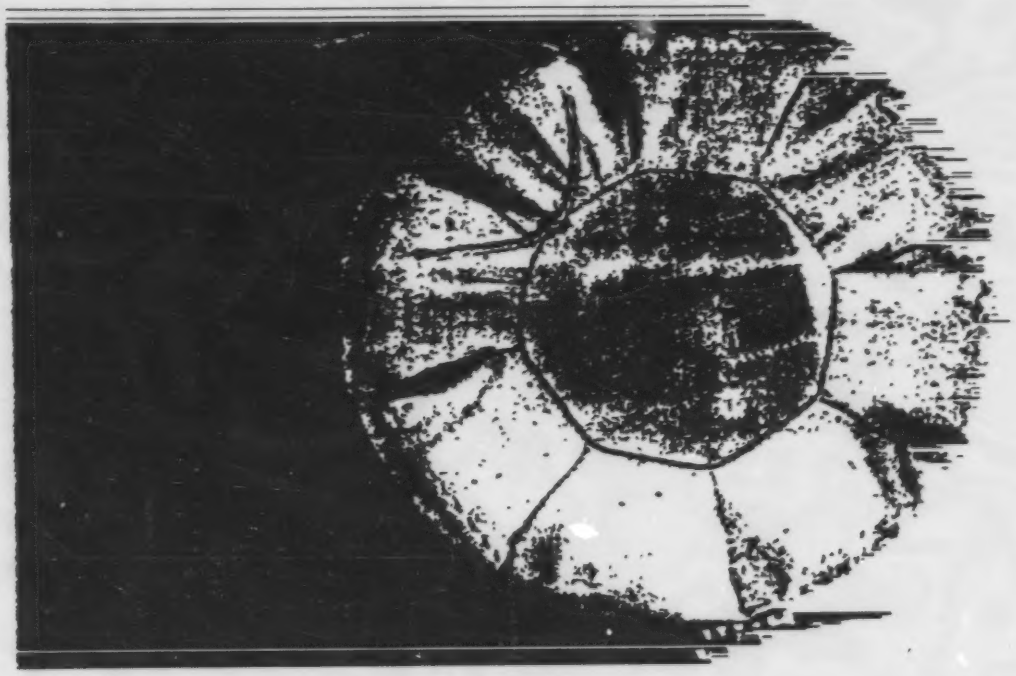
An ignition pad is then offered to close up the bag. The orientation of the ignition pad is important, and recommended practice is as follows:

1. Place the filled charge bag so that the bag seam is at the 12 o'clock position.
2. Orient the ignition pad so that the flap detail will be at the outside of the bag, and the black powder pockets are at the inside of the bag.
3. Align the flap so that the distance between it's sewn hinge and the bag seam is the shortest possible; and the edges of the flap run parallel to the line running from the 12 o'clock to the 6 o'clock position. This orientation may be viewed in the photograph given as figure 10-7.
4. Place the ignition unit into the bag so that it lies directly upon the propellant stack.
5. Apply water based wood glue to the exposed wooden ring as shown in figure 10-8.
6. Tighten the drawstring, secure it with a knot, and trim the excess cord.
7. Set the charge aside to allow the adhesive to set.

A photograph of a completed, stacked charge element is given as figure 10-9.

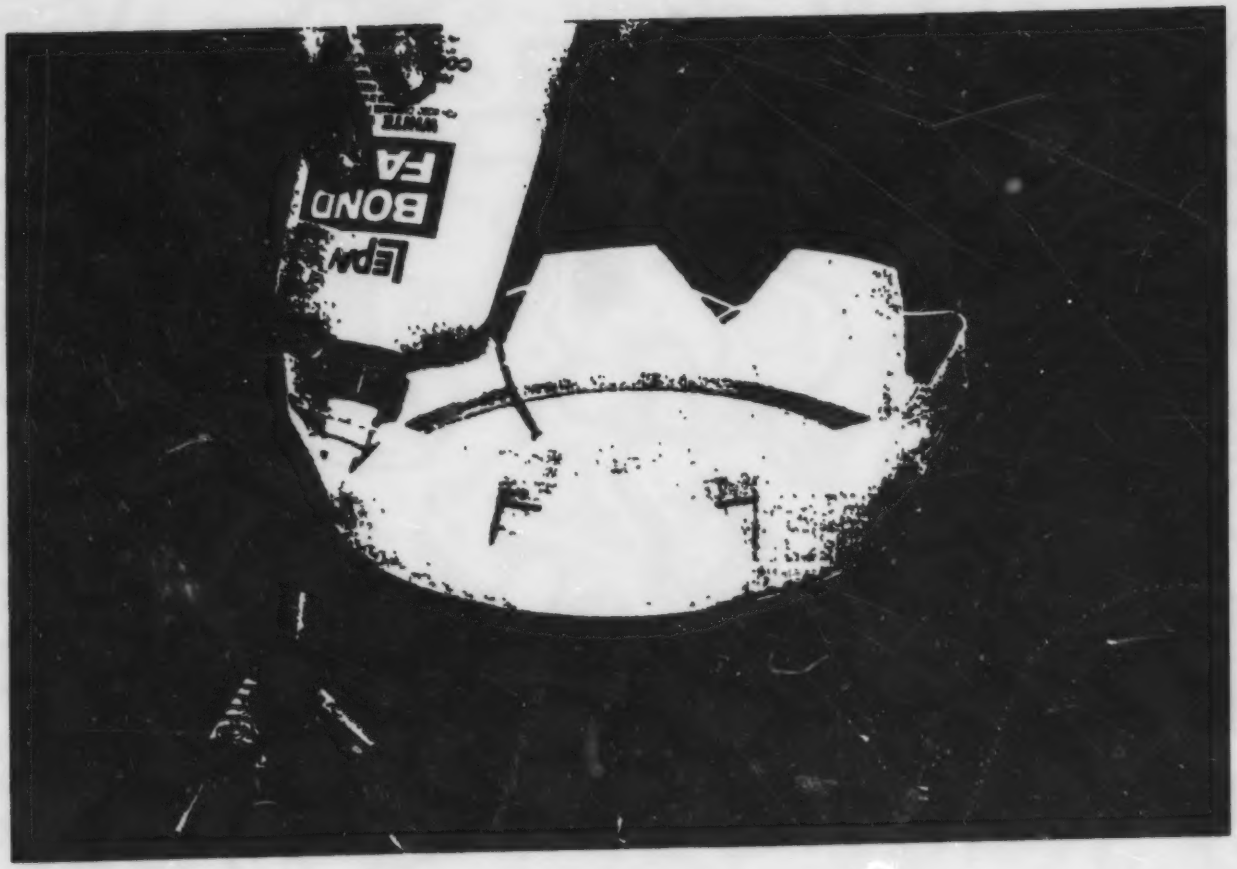
Figure 10-7 Igniter alignment

In the photograph the bag seam is at the top.
The flap hinge is near to this seam but this is hidden by the loops.
The flap edges run parallel to a diametrical line running (vertically), starting from the bag seam.



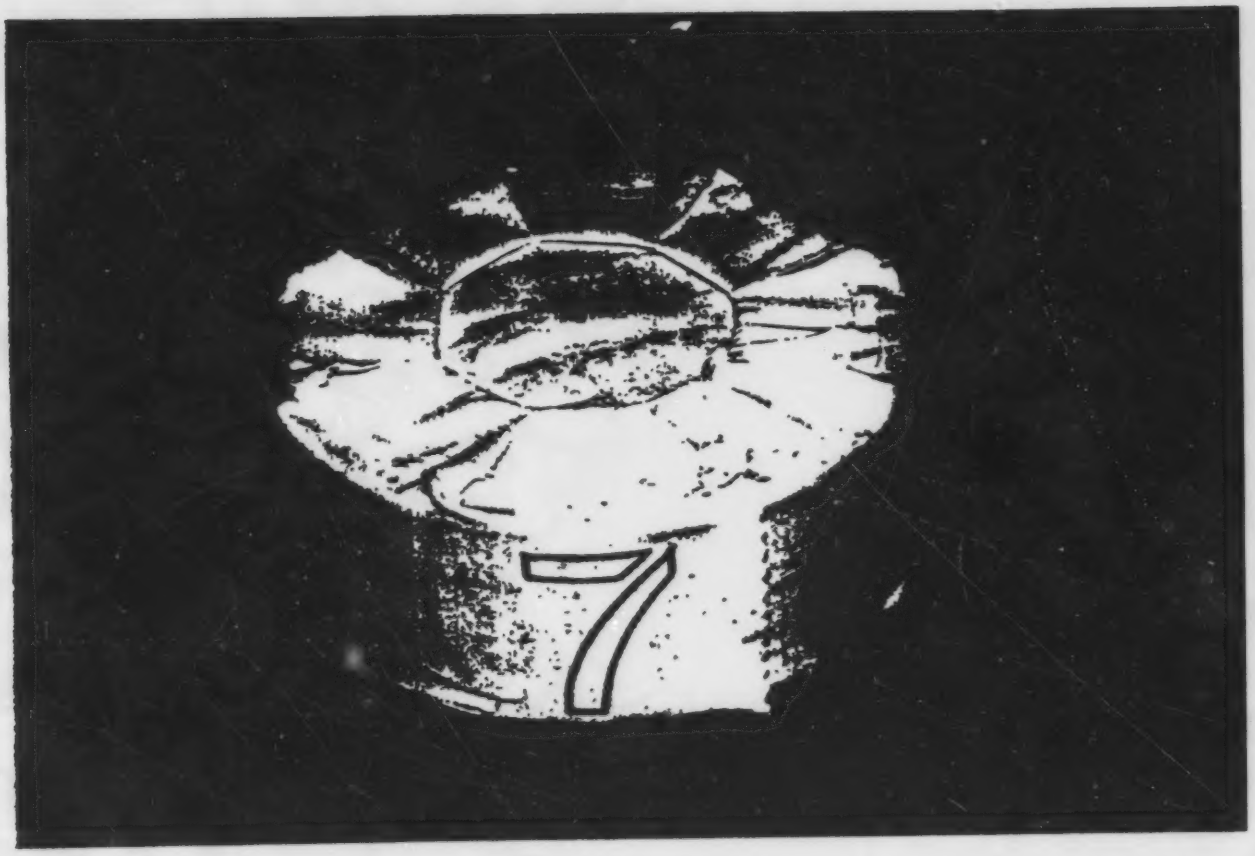
D.R.E.S. Photo 9806933

Figure 10-8 Application of adhesive to ignition pad, prior to closing up the propellant bag.



D.R.E.S. Photo 9806932

Figure 10-9 Exterior view of a stacked charge element



D.R.E.S. Photo 9806934

Part 3 Procedures for making charge bags and other elements

11.0 Wood parts

A thin plywood ring forms the base of each charge bag. These rings also form the spacer ends. One additional ring is intended to be placed between the charge and the breech plug. This is to protect the charge element adjacent to the breech from being damaged by the two projections at the breech plug face. A considerable number of these plywood rings are found in the make up of one propelling charge, as the following table reveals.

Table 11-1 Plywood ring schedule

Item	Quantity per Unit	Quantity per Charge
Number of bags per charge	10	
Number of rings utilized per bag	1	
Number of rings utilized in bags		10
Spacers required per charge	4	
Number of rings utilized per spacer	2	
Number of rings utilized in spacers		8
Number of rings employed at breech face		1
Total number of rings utilized per charge		19

A photograph of this ring part is included as figure 11-1.

Ring material is 1 / 8 inch thick, three ply, hardwood plywood. Rings are turned on a lathe to dimensions given in the following table.

Table 11-2 Bag Support ring dimensions

Outside diameter	6.250 inches
Inside diameter	3.750 inches
Width of ring	1.250 inches
Thickness of ring	0.125 inches

A full size image of one of these rings with dimensions at inspection is given as figure 11-2.

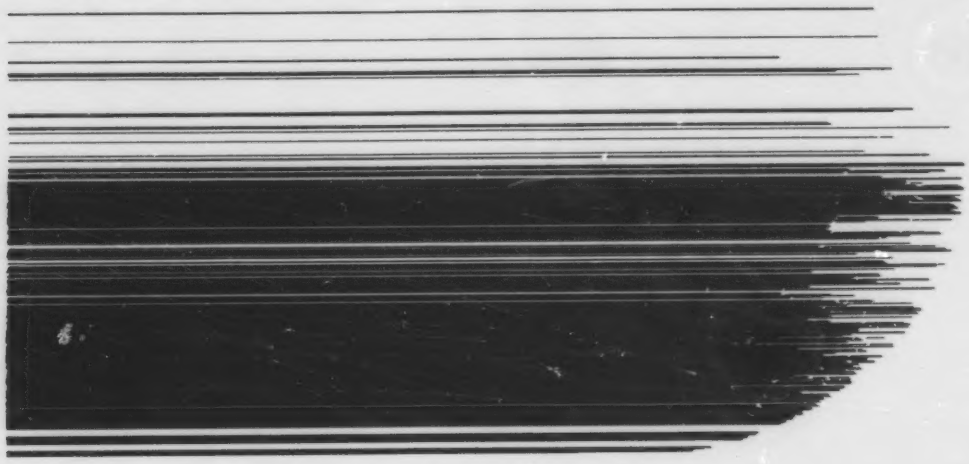
Another model of support ring forms a part of ignition pad assemblies. This part is lathe turned from plywood material identical to that used in making up bag support rings. The dimensions for ignition support rings are presented in table 11-3.

Table 11-3 Igniter support ring dimensions

Outside diameter	6.250 inches
Inside diameter	5.250 inches
Width of ring	0.500 inches
Thickness of ring	0.125 inches

The full size image of an ignition support ring is given in the photocopy presented as figure 11-3.

Figure 11-1 Bag support ring



D.R.E.S. Photo 9806923

Figure 11-2 Bag support ring dimensions

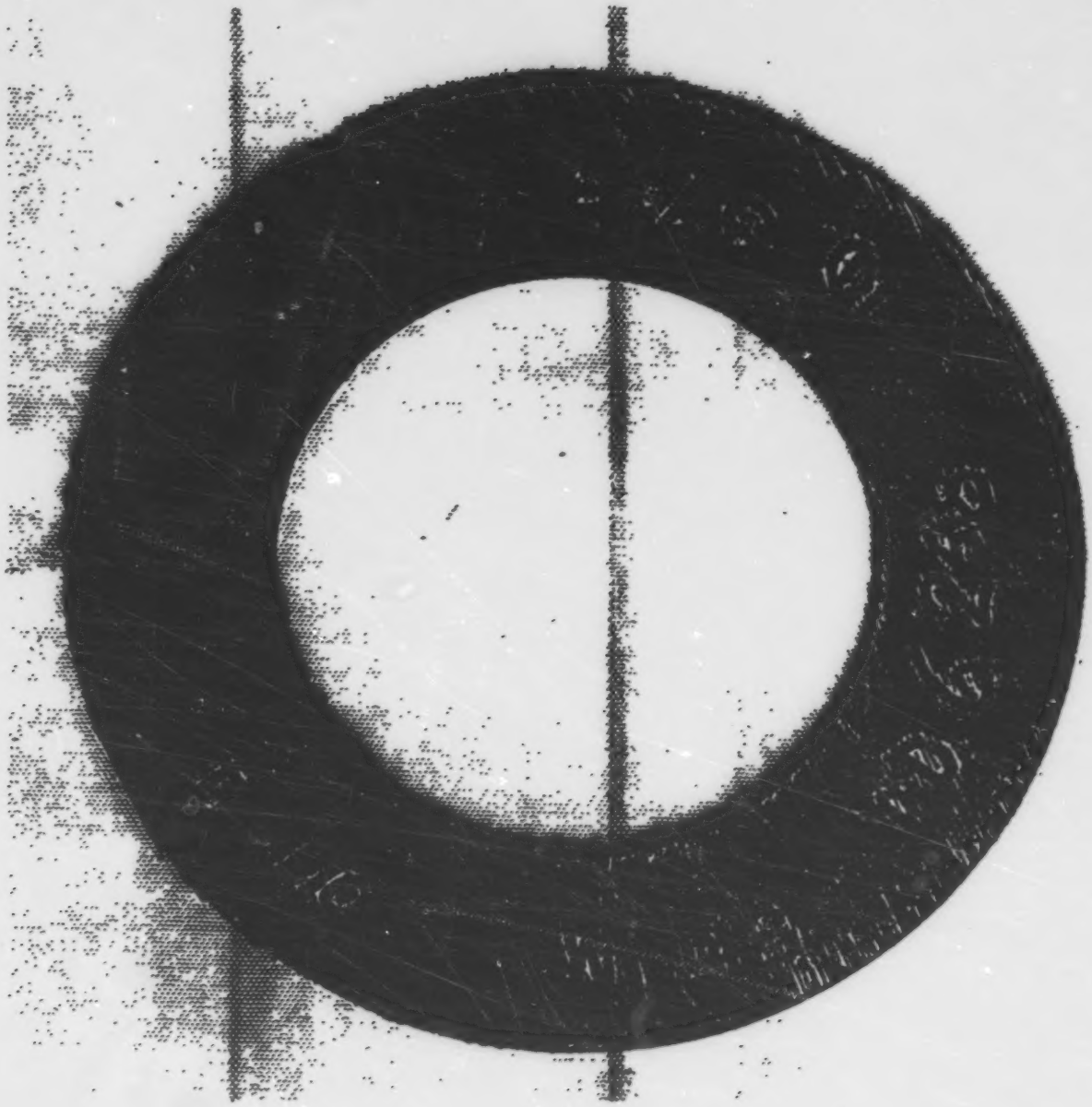
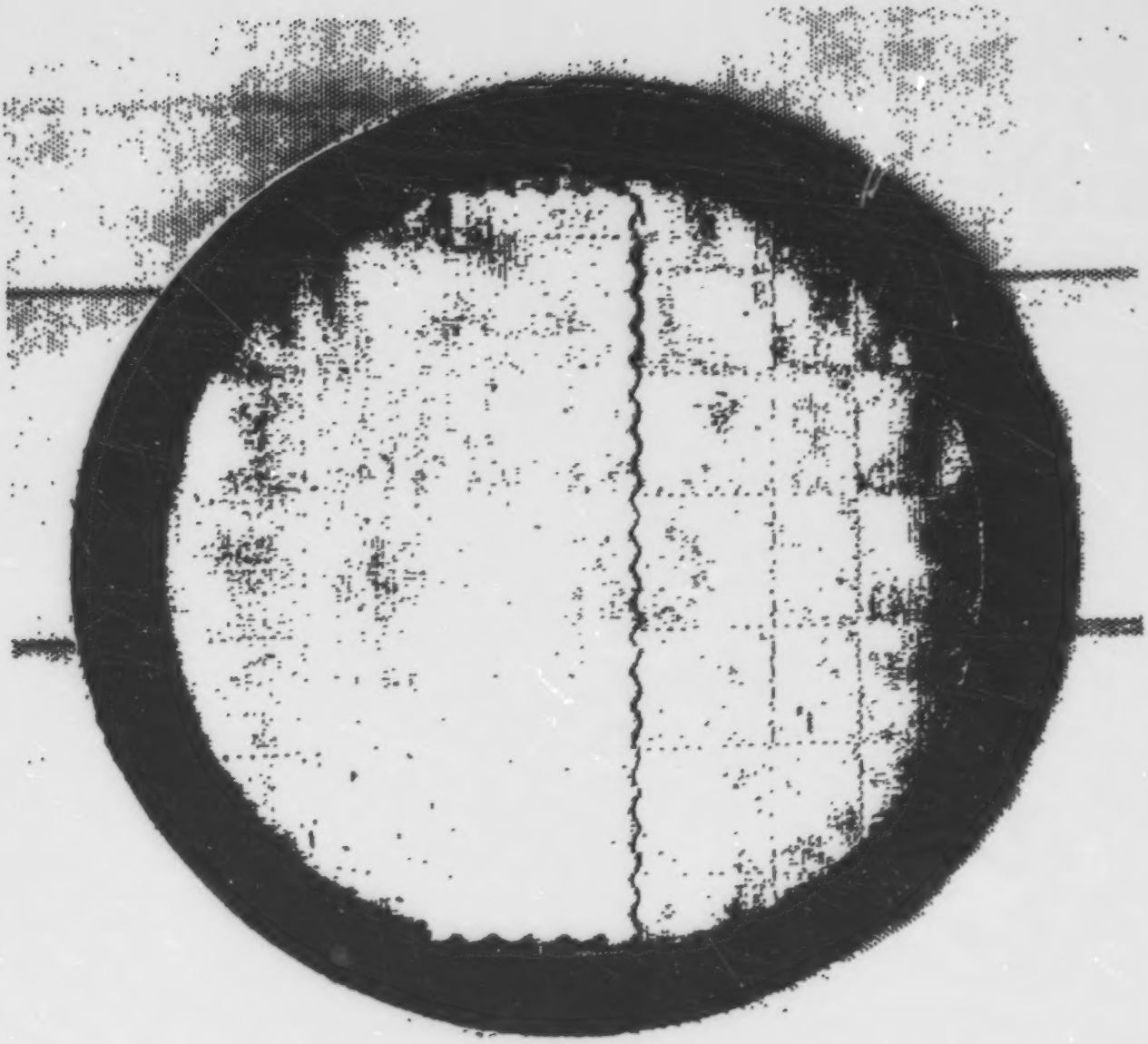


Figure 11-3 Ignition support ring



One ignition ring is required in the assembly of a completed bag. Since 10 bags make up one propelling charge, 10 ignition rings are required for each charge.

Spacers

Spacers maintain the propellant bags in a fixed position during the start phase of the charge burn process. Since the charge bags are in three lengths, and since the propelling charges are made up in different combinations of filled bags, the space between propellant bags is variable.

For a new gun, the distance between the breech face (when closed), and the base of a seated test slug is 33.628 inches. As the gun is operated wear will occur, and the shot start position will gradually shift forward, increasing this distance.

A charge will normally consist of ten propellant bags paired in five sets, with four spaces located between the pairs. The overall length of each of the spacers is reckoned as one quarter of the difference between the length of the powder chamber, and the combined length of the ten bags of propellant.

The length of a spacer is governed by the length of a set of six dowels. A set of four spacers is illustrated in the figures 11-4 and 11-5.

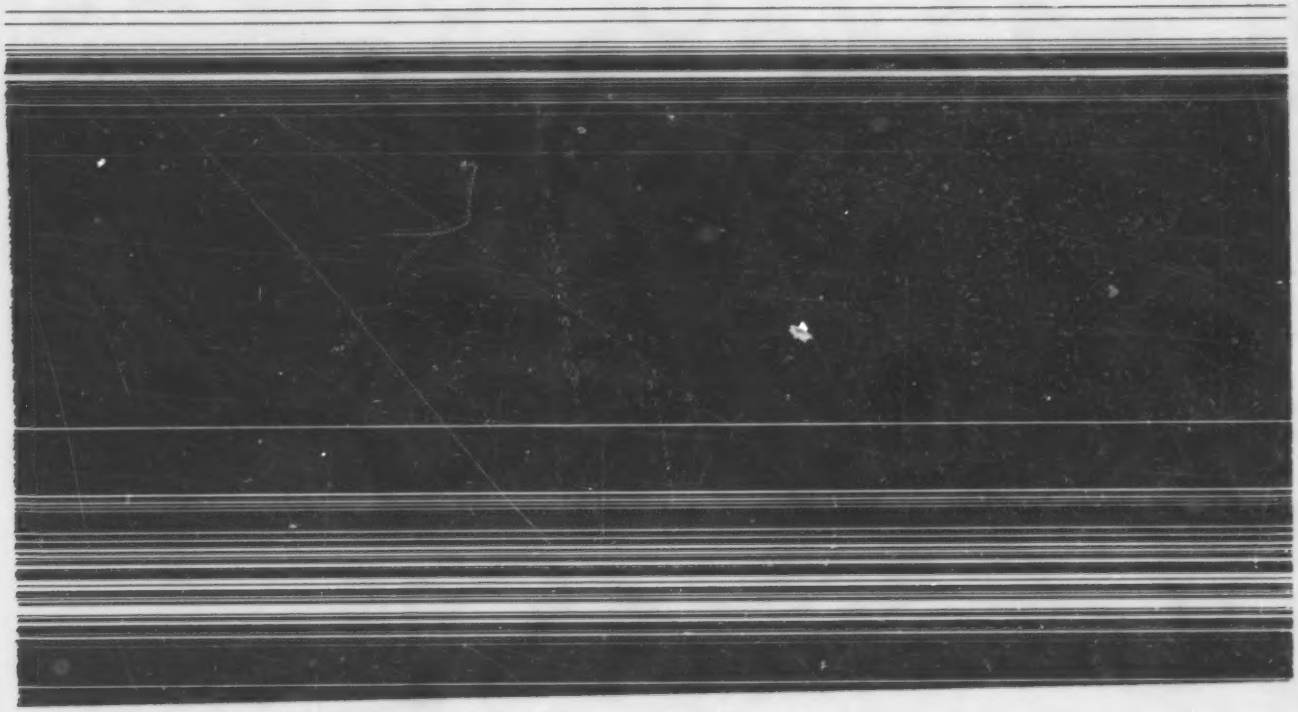
Maple hardwood is used to make up the dowel-columns. To obtain identical lengths, these are parted off on a lathe equipped with longitudinal travel stops.

The dowel-columns are fastened to the plywood rings using small brass nails; the brass material being specified to prevent damage to the gun bore.

Figure 11-4 Propellant bag spacers, side view

D.R.E.S. Photo 9806926

Figure 11-5 Propellant bag spacer set



D.R.E.S. Photo 9806925

12.0 Bag manufacture

Bag side panels

Three sizes of side panel exist to accommodate bags containing propellant in 7 layers, 8 layers and 9 layers.

To eliminate calculation and measurement work by the seamstress, a series of templates was produced. When laid out on the cloth, marked, cut, sewn, and trimmed in accordance with the notes attached as appendix A, perfect bags result.

A total of seven steps are outlined to complete manufacture.

Full size patterns for the templates are included in appendix B.

Igniter pads

Only one model and size are used, each propellant bag being identically equipped.

A total of five templates are required for marking, cutting, folding, sewing and trimming. A series of fifteen operations, given as notes, are outlined in appendix C. When these are completed in sequence, perfect igniter pads obtain.

Propellant bag bottoms

Propellant bag bottoms are produced using operation 1 of the igniter pad process, followed by operations 14 and 15.

Propellant bag assembly

Complete propellant bags are made up by bonding one bag bottom to the side panel. The bag bottom at assembly is oriented to have the fabric side at the interior of the bag, with the wood stiffening ring facing outwards. The correct fold distance is automatically obtained when the pinked cut edges are matched to the inside diameter of the support ring. This is illustrated in figure 10-1. Water based wood glue is employed to form this bond. Full size patterns for the templates used in igniter manufacture are included in appendix D.

13.0 Charge proving firing series

To bring the propelling charge into operation, planning for a series of tests was carried out. The test series comprises twelve firings, and features successive increases in performance. The details are given in appendix F.

The propellant arrangement, and the operating pressures presented, are drawn from the study of internal ballistics earlier covered in section 6.0 of this report.

References

1. Henry W. Miller, Lt. Col. U.S. Ordnance, "The Paris Gun", George C. Harrap & Co. Ltd. London, 1930.

2. Eugene D. Boyer, Leonard C. MacAllister, "Seven Inch HARP Gun-Launched Vertical Probe System: Initial Development", Memorandum Report No. 1770, Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, July 1966.

3. G.V. Bull, "Review of Experimental and Theoretical studies of the HARP Solid Propellant Ignition and Combustion Tube Launcher", Proceedings of the 12th. International Symposium on Shock Tubes and Waves, The Magnus Press, Hebrew University, Jerusalem, 1980.

4. Albert W. Horst, "Pressure Wave Phenomena in Large Caliber Guns", Progress in Astronautics and Aeronautics, Gun Propulsion Technology, AIAA 1988.

5. G.V. Bull and C.H. Murphy, "The Paris Guns and Project HARP", Verlag Mittler & Sohn, Herford and Bonn, 1988.

6. J. Maillette, "Pinball: A Standard Lumped-Parameter Interior Ballistic Code", D.R.E.V. Report 4628/90, December 1990.

7. Ronald A. Sassé, "Black Powder", Progress in Astronautics and Aeronautics, Gun Propulsion Technology, AIAA 1988.

8. Eli Freedman, "Thermodynamic Properties of Gun Propellants", Progress in Astronautics ans Aeronautics, Gun Propulsion Technology, AIAA 1988.

9. Fundamentals of Ballistics, Special Text, ST 9-153, U.S. Army Ordnance Center and School, Aberdeen Proving Ground, Maryland, 1964.

10. Technical Manual, 155 mm Gun, M-2, TM 9-350, U.S. War Dept. 7 May 1945.

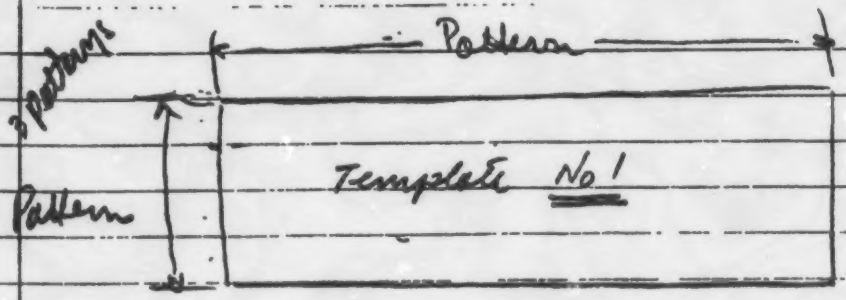
11. Blasters Handbook, 6th. Edition, C-I-L Inc., North York, Ontario, 1987

Appendix A

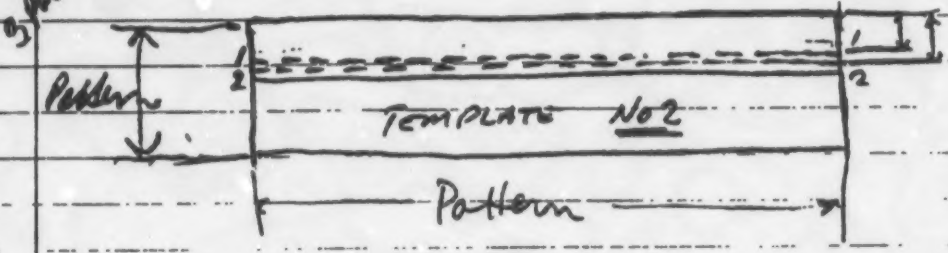
Procedures for the manufacture of propellant bags

PROCESS FOR SIDE PANELS

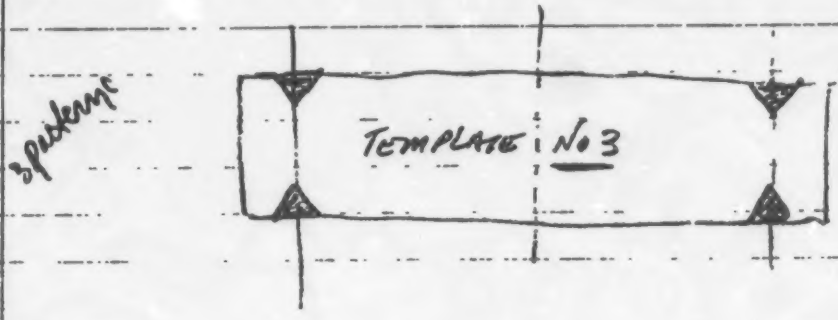
PAGE 1 OF 2



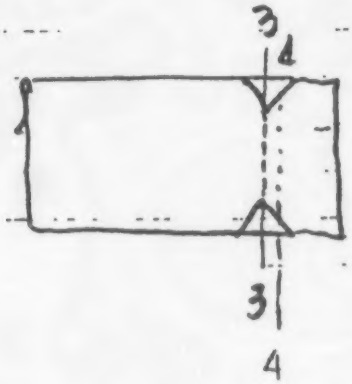
MARK FROM Pattern & Cut Matl To Plow



Fold over pattern & Sew 1-1 & 2-2



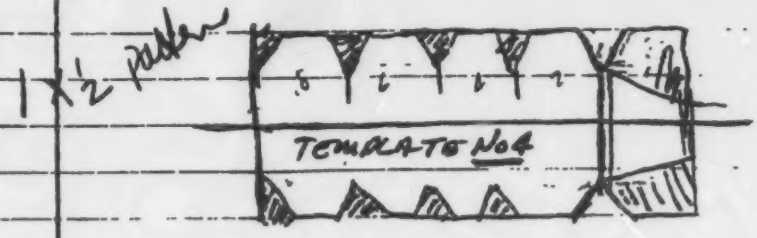
Mark and Cut out 4 ▽'s



Fold
Align Cutouts
Sew 3-3
Sew 4-4

PROCESS

PAGE 2 OF 2

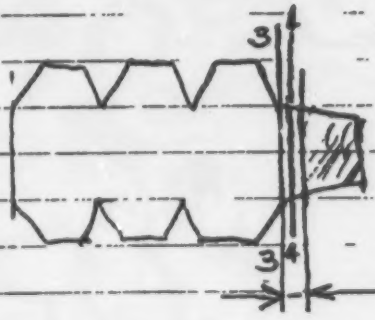


MARK FROM PATTERN

¼" Cut

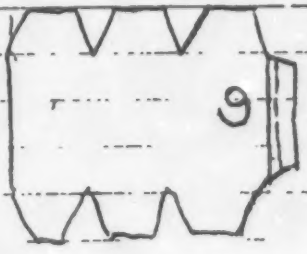
5 TOP CUT OUTS
(Double Thickness)

5 BOTTOM CUT OUTS
(Single Layer)
(Flip Template for Bottom Cut-Line)



TRIM EXCESS

TRIM LINE 3/4 INCH FROM SEW LINE 3-3



MARK SIZE No. USING STENCIL ADJACENT TO SEAM

Appendix B

Patterns for templates
for marking, cutting, folding, and sewing propellant bags

Charts held at DRDKIM

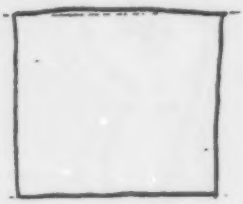
If you would like to view charts, please contact DRDKIM 2-2

Appendix C

Procedures for the manufacture of ignition pads

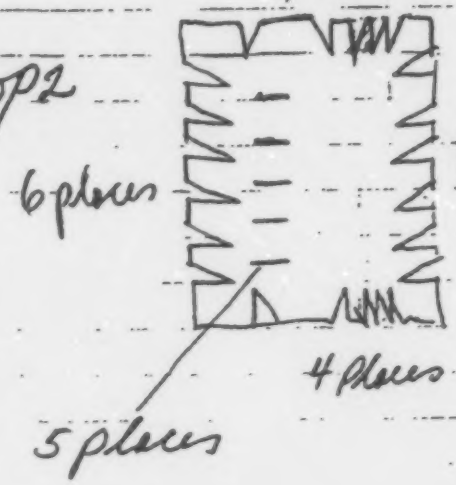
PROCESS, Igniter Pkg

op 1



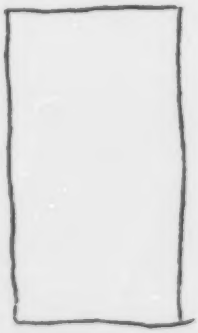
Cut out Square 7/8 x 7/8 Base
using template 1

op 2



Mark 6 lines R.H.S
6 lines L.H.S
4 lines TOP
4 lines Bottom
5 lines Center lg
using template 2

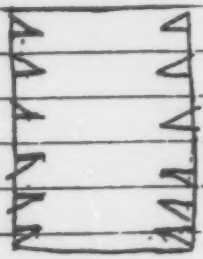
op 3



Cut out pocket
using Template 3
all Edges Pinked

Process, Igniter Pkge

op 4

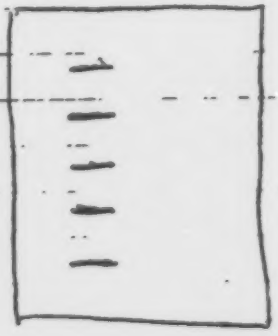


on Pocket,
MARK 6 lines, R.H.S.
6 lines, L.H.S.
using template 4

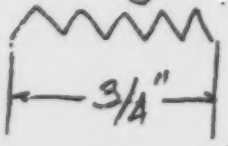
op 5

Cut out Flap
using template 5

op 6

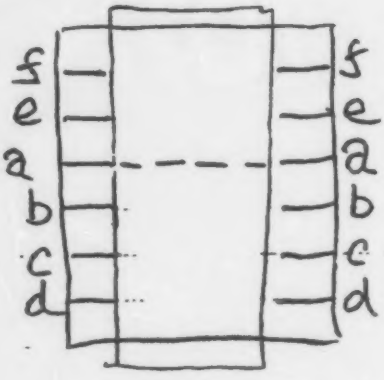


In Base Square
Cut Slit along
5 short lines
earlier Marked.
Perking Cut desired



3/4 in. long
each.

op 7 Sewing



Match line a-a on pocket to lines on base square. Sew Pocket To base along line a-a. Ends of lines Marked on base Square serve to position pock

op 8

Gather pocket and le up line bb to match Pocket. Sew along b-

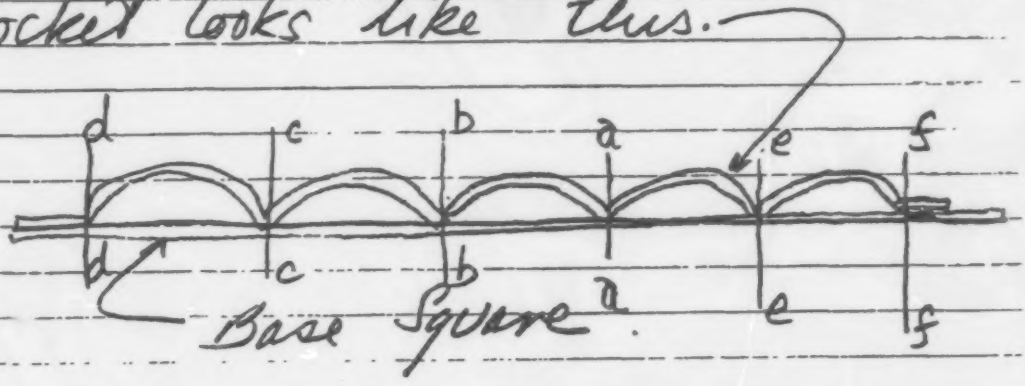
op 9

Continue gathering pocket Matching lines on pocket to lines m/a· kid upon base square

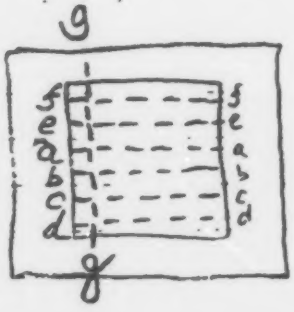
Op 10

Sew from near center of pocket (line a-a) progressively working outward, in sequence a, b, c, d, e, f.

Pocket looks like this.

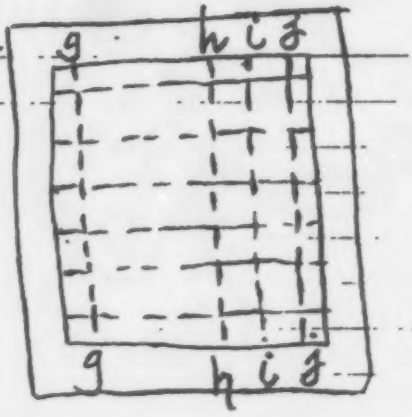


Op 11



Fold over pocket ends & sew between marked lines g g across seams a through f

op 12



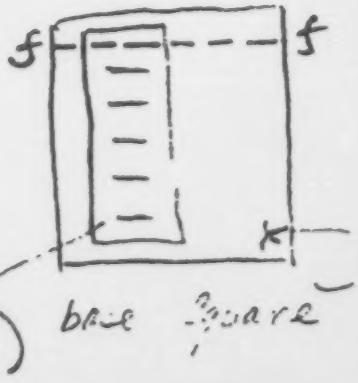
Fold R.H.S. of Pocket & Sew between Marker lines h h, i i and j j.

Seams h h & i i wide Stiched

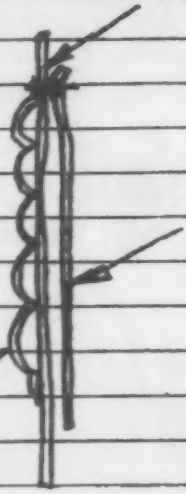
op 13

Sew Flap.

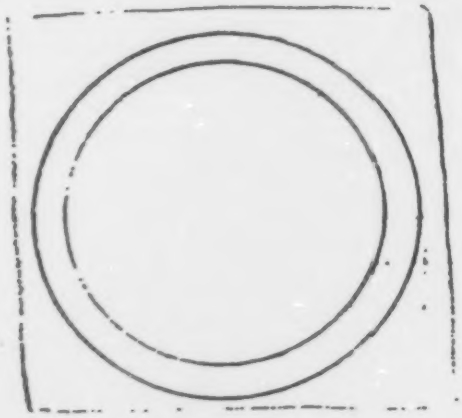
Flip over Sewn assembly. Center Flap over slits Cut into base Square in operation # 6 Sew flap to base Square along seam f f



Op 13, Cont'd

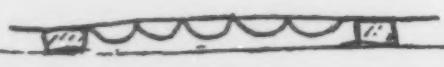


Op 14



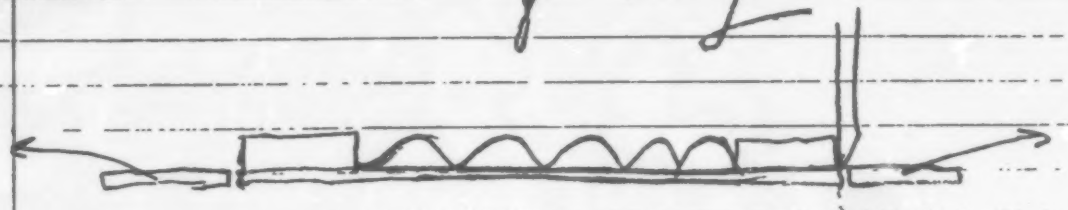
Bonding

apply glue to Wood Ring. Place Sewn Square Assy (Pocket downward onto ring and allow glue to set.



op 15 **Trim**

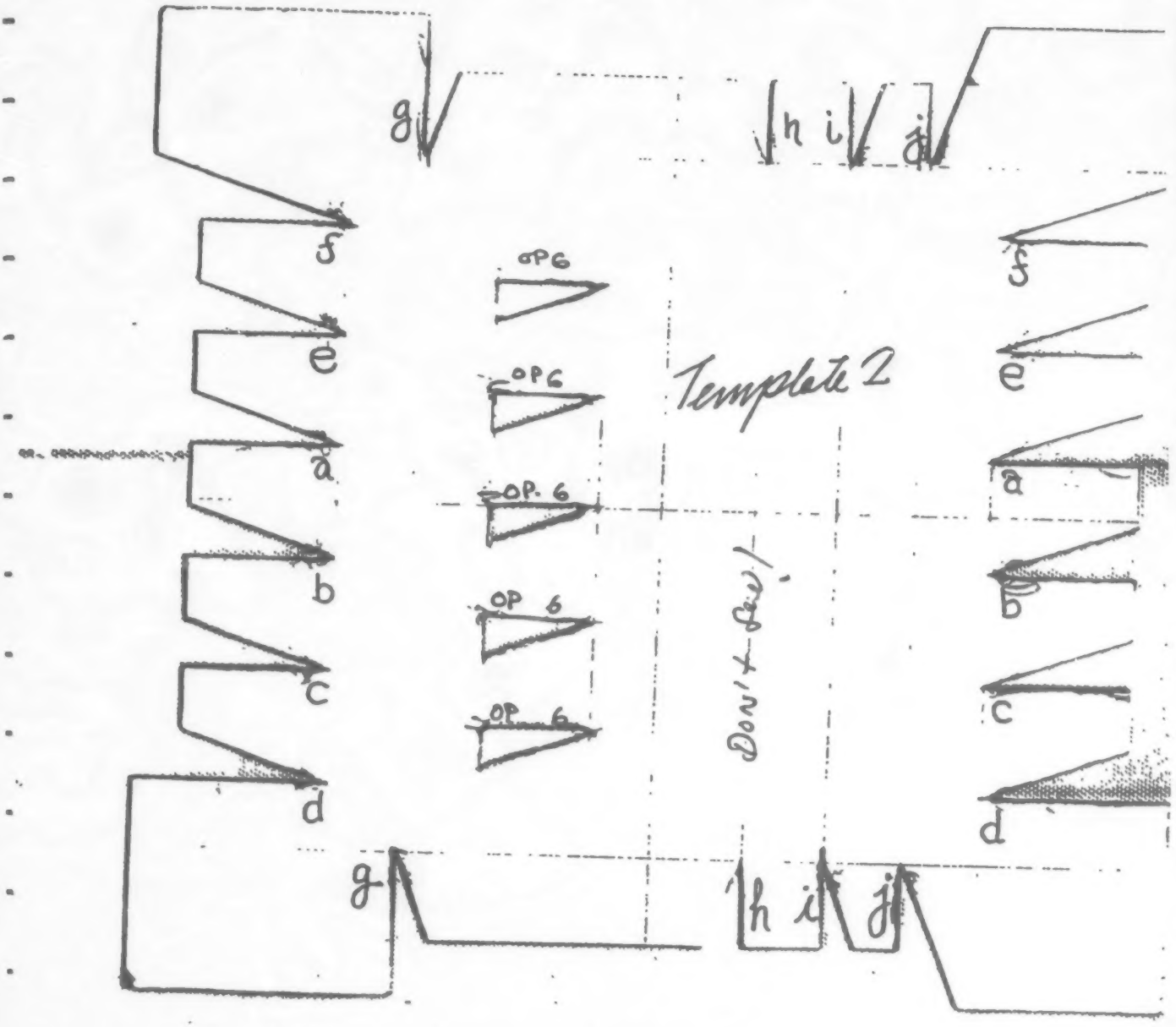
After glue has set,
Trim excess Material
from outside diameter
of Ring

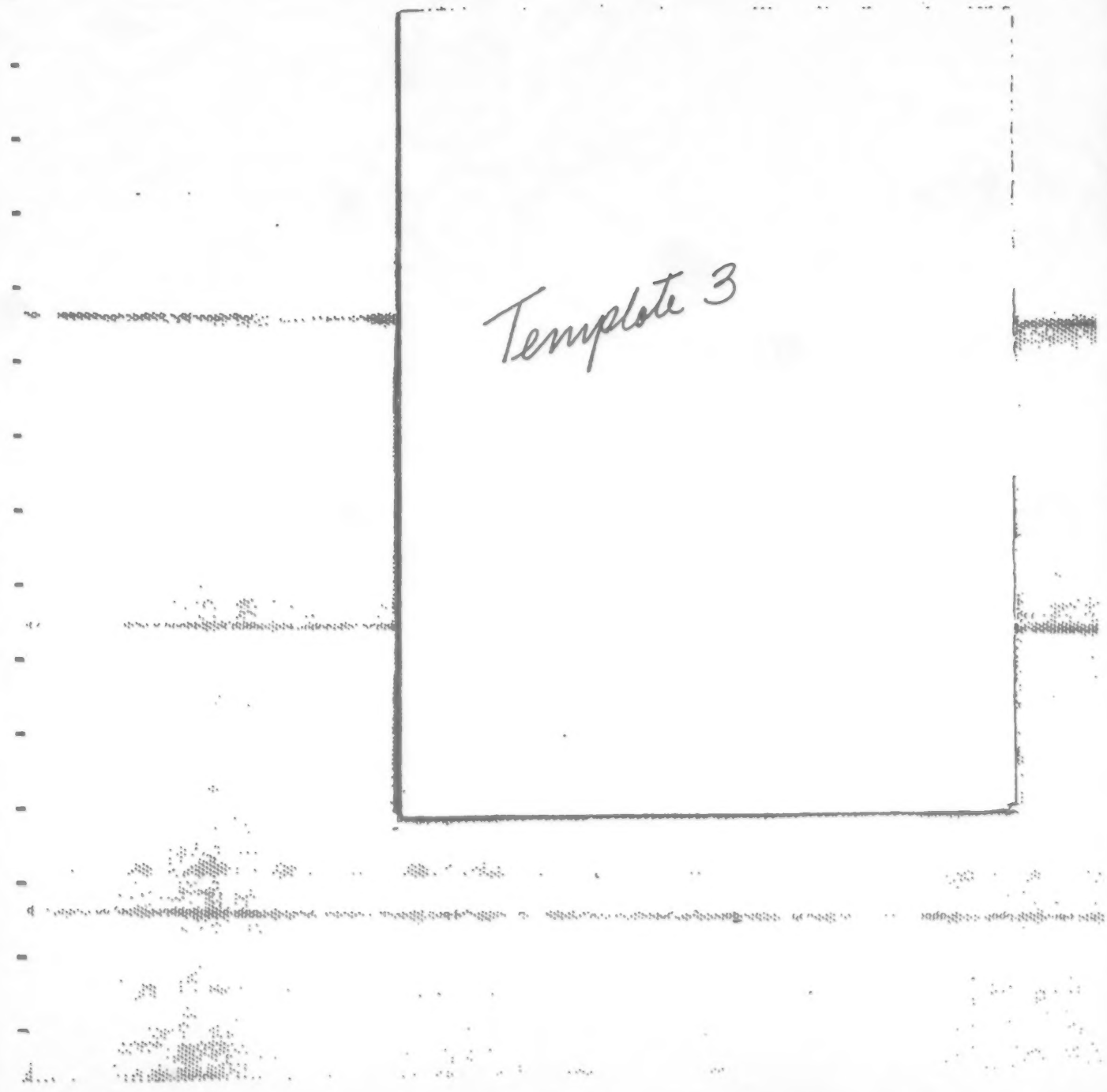


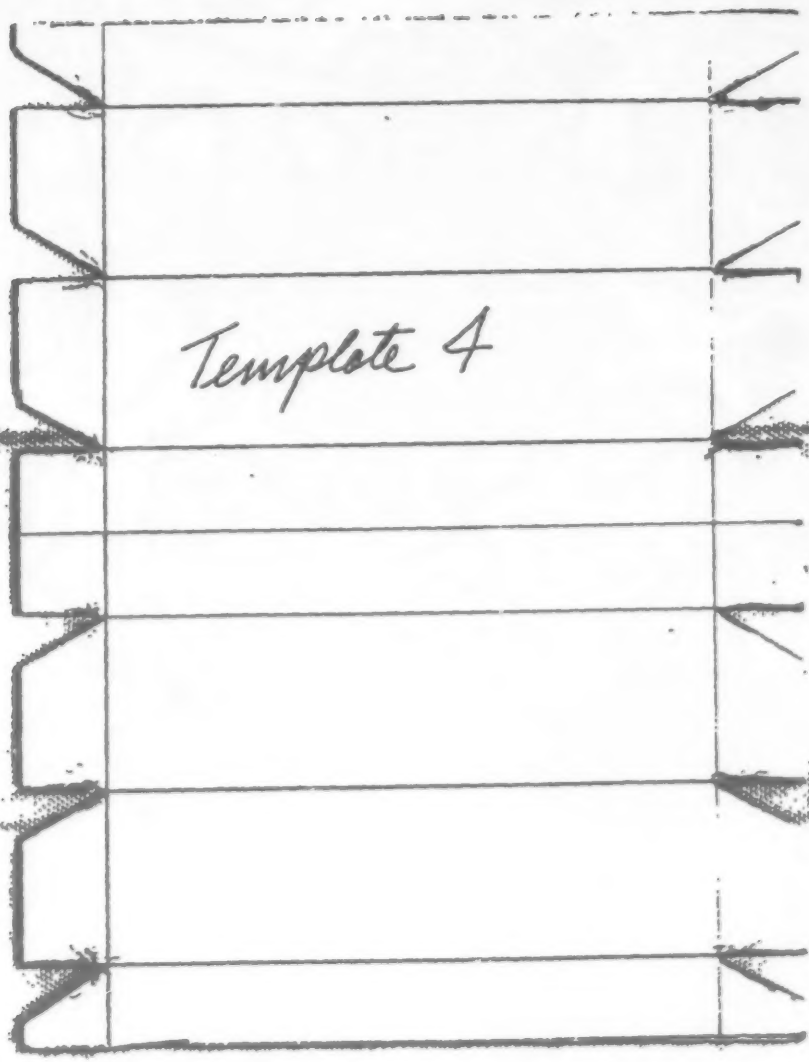
Appendix D

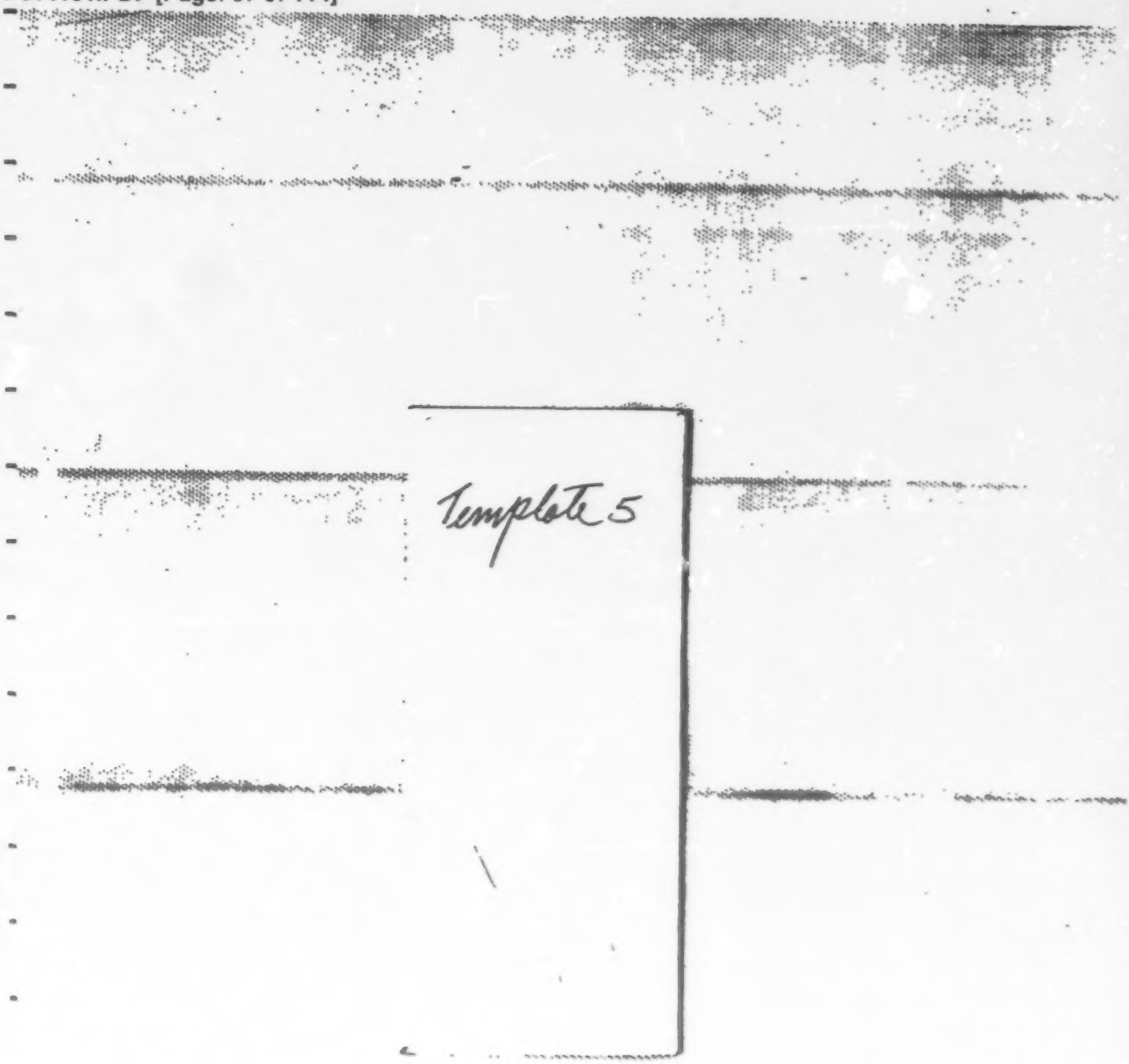
Patterns for templates
for cutting, marking, folding, and sewing ignition pads

Template 1


g
h i j
f
e
a
b
c
d
OPG
OPG
OP. 6
OP 6
OP 6
Template 2
Don't Bend!
f
e
a
b
c
d
g
h i j


Template 3


Template 4


Template 5

Appendix E

Propellant grain measurement results

DRES FOS FDDS

WORK SHEET

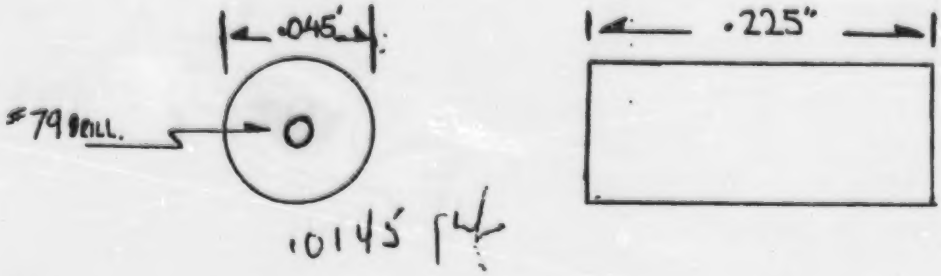
TO:		FILE NO:	
FROM:		DATE:	
SUBJECT:			
PROJECT/TRIAL:			
SITE NAME:		BLDG.NO:	
SITE LOCATION:		SHEET	OF

Propellant Grain Size

Simon / David :-

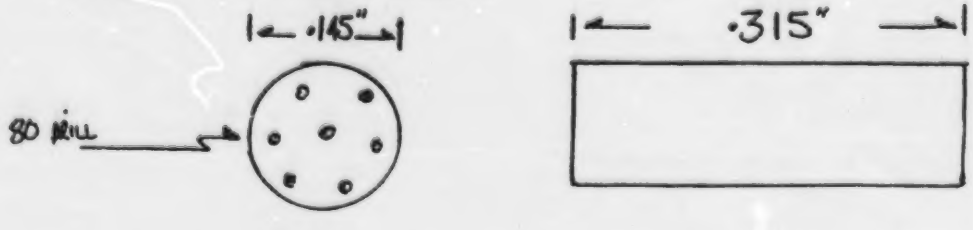
As discussed, have one your grain sizes:

From Charge Bag 1. (105) Single Perf.:



.0145" ✓

From Charge Bag 6 Seven Perf.



See over

As you've probably noticed I gave a hole/Perf size on each grain as a #79 drill bit and a #80 drill bit respectively — I did not have a micrometer with me at the time, the #80 was, and is a rather tight fit - but was the best I could do in a pinch —

attached are the two Drill bits —

will be at local 4781 till 3:15

Ken P.

— #79

— #80

.01

.0145 = #79

.0132 = #80

.130

Ken Kihn, 01:10 PM 2/24/98 , Weiss Propellant Data

Return-Path: <Ken.Kihn@dres.dnd.ca>
X-Sender: kkihn@mailhost.dres.dnd.ca
Date: Tue, 24 Feb 1998 13:10:55 -0700
To: "Murray, Dr Stephen" <Stephen.Murray@dres.dnd.ca>
From: Ken Kihn <Ken.Kihn@dres.dnd.ca>
Subject: Weiss Propellant Data

Steve:

Information for David's Trials:

Propellant Data Sheet

Part 1 Single Grain Data

Weight of:	Trial 1	Trial 2	Trial 3
1 grain	see note a	see note a	see note a
10 grains	1.0 grams	1.0 grams	1.0 grams
100 grains	11.0 "	11.0 "	10.8 "

Avge = 10.933

Single Grain Dimensions:

Lot 1	Dia 0.1390 "	Length 0.3130 "	(inches)	
	0.1365 "	0.3045 "		
	0.1385 "	0.3035 "		
	0.1420 "	0.3125 "		
	0.1350 "	0.3025 "	Avge = .3072	
Lot 2	Dia 0.1400 "	Length 0.3035 "		
	0.1375 "	0.3105 "		
	0.1370 "	0.3115 "		
	0.1350 "	0.3165 "		
	0.1355 "	0.3100 "	Avge = .3104	

Part 2 Random Filled Volume

Weight of:	Trial 1	Trial 2	Trial 3
Random filled Container (1)	1,860 grams	1,860 grams	1,860 grams
Container (1) tare	188.0 "	188.0 "	188.0 "

Ken Kihn, 01:10 PM 2/24/98 , Weiss Propellant Data

Part 3 Weight of stacked Propellant Array

Weight of:	Trial 1 (Row 1)	Trial 2 (Row 2)	Trial 3 (Row 3)
Filled test Container (2)	273.6 grams	447.7 grams	621.7 grams
Container (2) tare	96.9 grams	96.9 grams (see note f)	96.9 grams

Notes: a. Weight of 1 grain for Part 1 is estimated. ESEG scale could not measure accurate weight of small propellant sample;

b. Photo's have been taken of the stacked array and of the filled test container. Photo's have not been developed as yet and will be forwarded to You (Steve) once ESEG receives them;

c. Tests were conducted with only 2 lots of 105mm propellant. 3 lots of propellant were not available;

d. dia and length of 10 separate grains were measured (5 from each lot);

e. scales utilized: Cave 0-2 Kg Beam Scale, last calibrated 28 May 97, Ohaus 0-20 Kg Beam Scale, last calibrated 28 May 97; and

f. this row was counted and contained 1588 grains of propellant.

Please relay this data to David Weiss.

CWO Kihn sends

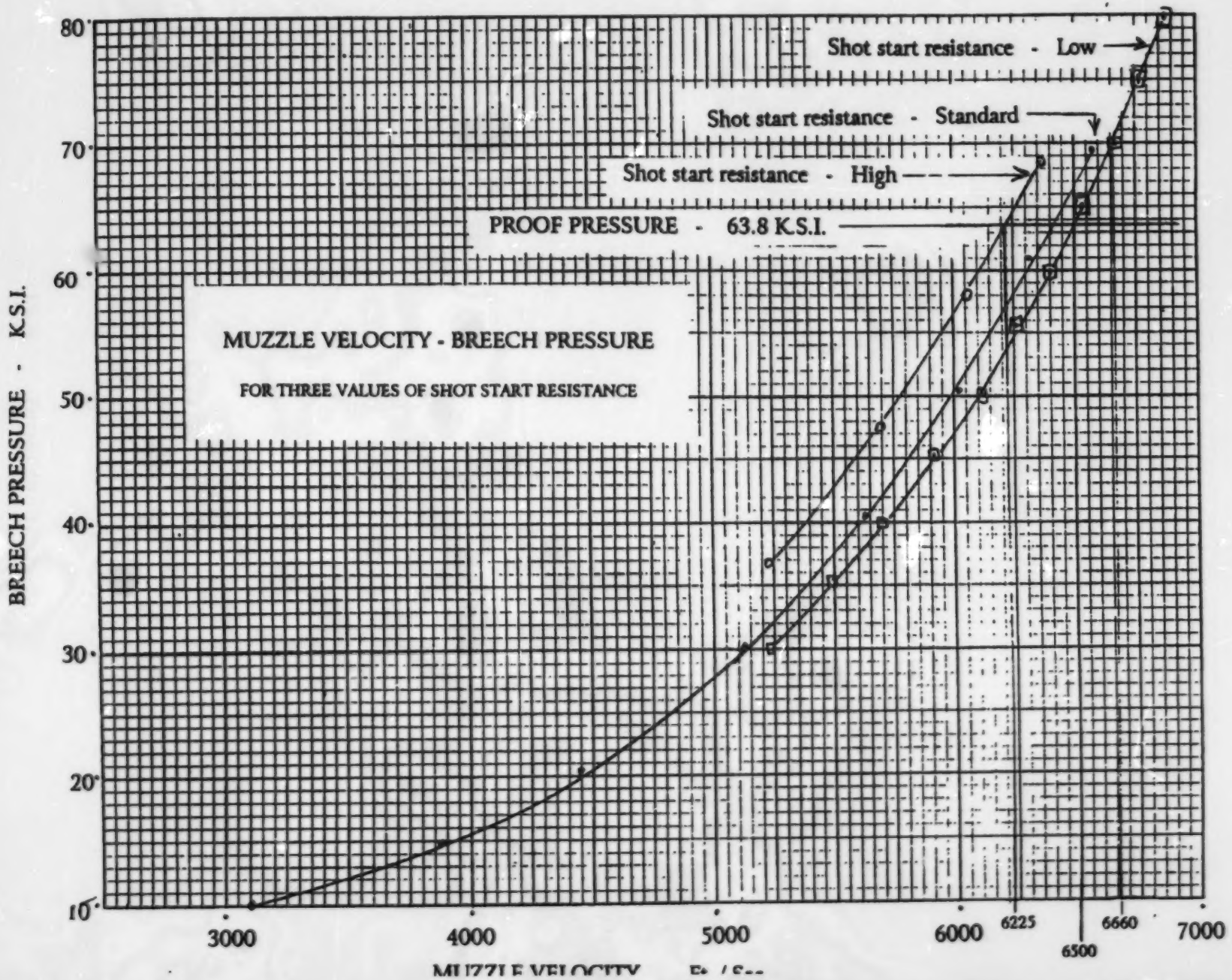
Appendix F

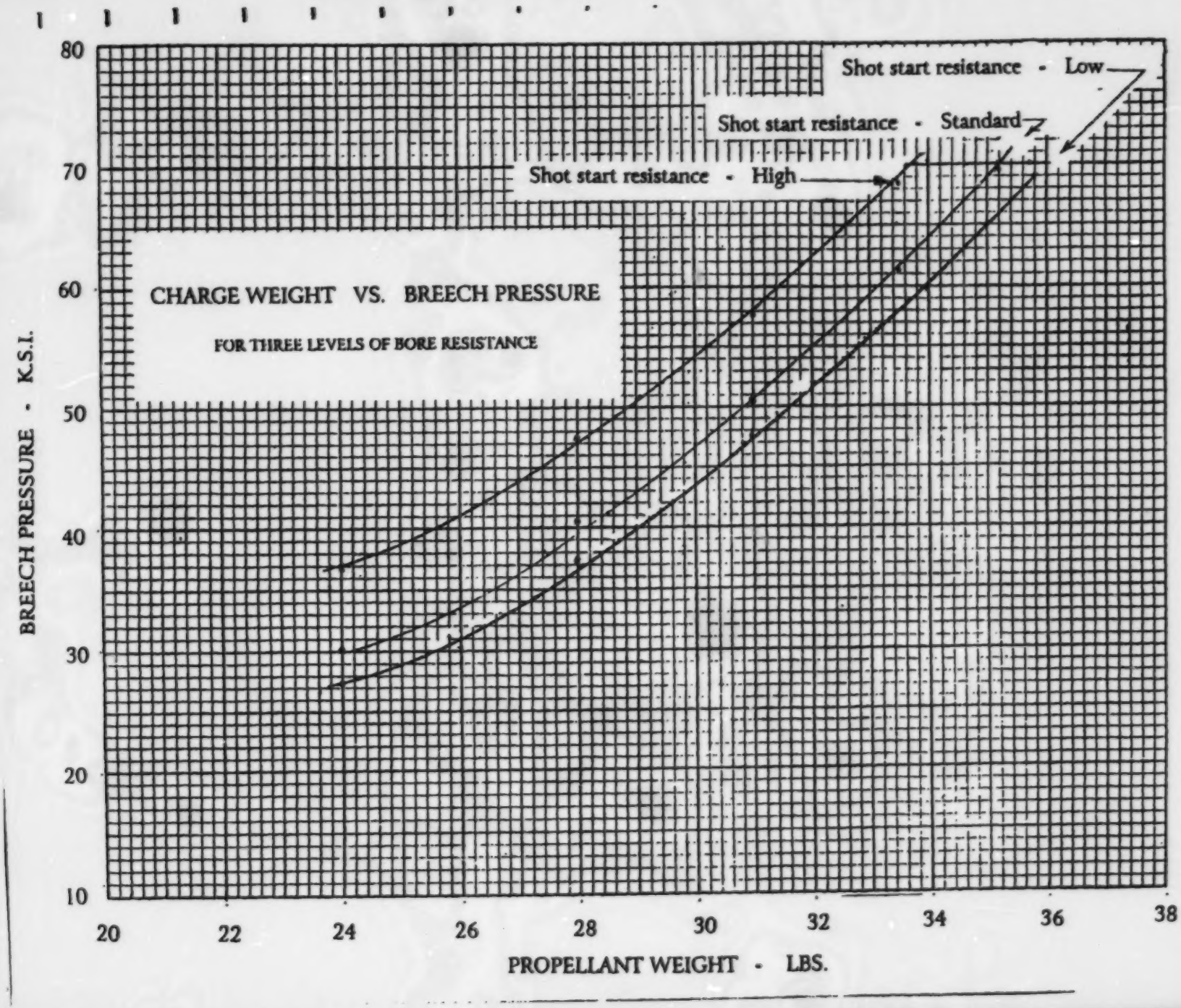
Predicted charge performance

and

An outline of a charge test firing series

P514161.PDF [Page: 104 of 114]





P514161.PDF [Page: 105 of 114]

Results of a computer simulation

Conditions:

Gun, 155 mm, M-185 barrel

Propellant, M-1,

Grain geometry, 7 Perf, 0.145" dia., 0.315" long, perforation Dia. 0.013"

Propellant weight, 35.22 Lbs.

Bore resistance, "Low"

Projectile weight, 7.793 Lbs.

Results:

Maximum breech pressure, 66,114 P.S.I.

Velocity at muzzle exit, 6562 Feet per second = 2000 Meters per second

Percent of propellant burnt, 98.83%

Time from shot start to maximum pressure, 2.30 Milliseconds

Time from shot start to muzzle exit, 5.32 Milliseconds

Breech pressure at muzzle exit, 15,174 P.S.I.

GUN AND PROJECTILE -	PROPELLANT	TRAVEL RESISTANCE
CALIBER 6.163	MASS 35.220	.000 2000.000
CHAMBER VOLUME 1186.610	GAMMA 1.267	.520 2475.000
TRAVEL 199.180	FORCE *********	1.040 1625.000
PROJECTILE MASS 7.783	FLAME TEMP. 2449.000	199.180 600.000
———————	COVOLUME 30.620	———————
GRAIN GEOMETRY: 7PF	COEFFICIENT .002	FIT: BURN RATE 1.000
LENGTH .315	EXPONENT .710	FIT: FRICTION 1.000
DIAMETER .145	SOLID DENSITY .057	FIT: FLAME TEMP. 1.000
PERFORATION .013		FIT: BURN RATE (T) 1.000

CONDITIONS AT		START	SHOT PRESSURE	MAXIMUM ACC.	MAXIMUM BURNOUT	MUZZLE EXIT
TIME	ms	.26	2.30	2.30	.00	5.32
BREECH PRESSURE	psi	2202.93	66114.16	66114.16	.00	15174.65
AVERAGE PRESSURE	psi	2159.30	51179.29	51179.29	.00	11896.13
MEAN GAS TEMPERATURE	K	2337.38	2125.01	2125.01	.00	1377.92
PROJ. ACCELERATION	g	219.48	75128.84	75128.84	.00	15979.27
PROJ. VELOCITY	ft/s	.07	2434.80	2434.80	.00	6562.55
PROJ. TRAVEL	ins	.00	17.48	17.48	.00	199.37
% PROPELLANT BURNED			.60	40.20	40.20	.00	96.83

Notes on the Propelling Charges for Supersonic Combustion Field Trials

1.0 The propelling charges for gun launching of the supersonic engine may be considered to be made up in layers.

2.0 Each layer consists of 1691 grains of propellant, stacked in orderly fashion, each grain in contact with the others adjacent, and formed into a circle of 6.312 inches in diameter.

3.0 When packing propellant to form one layer of an assembled charge, it is not neccessary to count the grains. Since the weight of one layer is 185.395 grams, to obtain propellant sufficient to pack one layer all that is needed is to weigh out 185.395 grams.

4.0 The maximum charge thought to be possible at the present time will consist of 89 layers of stacked propellant.

5.0 Due to ignition requirements, and the need to be able to vary the performance of the charge, it is not practical to assemble a charge as a single unit of "n" layers.

6.0 To accomodate ignition needs, and to be able to control gun launch performance, the charge is divided into three standard increments, each of which is packed into a special charge bag. In terms of layers these bags contain 7 layers, 8 layers, or 9 layers of stacked propellant.

7.0 To form an assembled charge of "n" layers, all that is required is to select the requisite number of charge increments of one, two, or even three of the different types.

As an example, one charge could be made up from two increments of 7 layers each and eight increments of 8 layers each. Such a charge could be characterized as follows:

a. The total number of increments is 10.

b. The charge contains 78 layers.

c. The weight of propellant is 31.8 lbs.

As a matter of interest, this particular charge is planned as test No. 3 in the initial series of charge performance trials, (firing test slugs), with performance predicted as follows:

Breech Pressure: 54,319 lbs. / sq. Inch.

Launch velocity: 6129 ft. / sec. = 1868 m. / sec.

8.0 In the chart following, we present a firing plan for field trials consisting of 12 tests in total. These tests are divided into four groups of 3 shots each. These are characterized below.

Group 1 Tests 1, 2, and 3.

Objectives: 1. To determine that the propellant ignition arrangements are functioning properly.

2. To determine that the charge behavior during burning is satisfactory.

3. To measure the performance of the charge.

Group 2 Tests 4, 5, and 6.

In this group of shots the objective is to bring the charge into high performance operation.

Group 3 Tests 7, 8, and 9.

For group 3 tests, the objectives are:

1. To use shot 7 to confirm the maximum performance acheived (i.e. shot No. 6), and to establish and observe the nature of the charge with regard to repeatability.

2. To extend performance levels of the charge if this is thought to be required.

Group 4 Tests 10, 11, and 12.

This group is planned as the flight trials of the supersonic combustion engine. For planning purposes it is shown in the chart following as being carried out with increments having 86 layers; but the size of this charge really depends upon the results of the earlier trials.

9.0 As a first step, we suggest that tests 1 through 6, (i.e. groups 1 and 2), be carried out as given in the chart, keeping flexible the plans for the later firing of groups 3 and 4. These latter groups are made up of 8 layer and 9 layer charge increments only. It will therefore be possible to arrange for any charge desired using a combination of 8 and 9 layer charge increments.

10.0 In the on-going charge assembly work at H.M.G. we reccomend that the increments be made up in accordance with the needs of tests 1 through 6 in the sequence shown on the attached chart. This work should be continued following the outline for groups 3 and 4.

11.0 FIRING PROGRAM FOR SPACED CHARGES

	Pressure in lb /sq. in.	Launch velocity m / sec	Total No. of Layers	No.of 7 layer Bags	No.of 8 layer Bags	No.of 9 layer Bags	Total No. of Bags
Group 1 Test No.							
1	30,000	1595	62	2	6	---	8
2	40,000	1742	71	1	8	---	9
3	50,000	1863	78	2	8	---	10
Group 2 Test No.							
4	55,000	1911	81	---	---	9	9
5	60,000	1951	84	---	6	4	10
6	63,800	1983	86	---	4	6	10
Group 3 Test No.							
7	63,800	1983	86	---	4	6	10
8	72,100	2044	89	---	1	9	10
9	72,100	2044	89	---	1	9	10
Group 4 Test No.							
10	63,800	1983	86	---	4	6	10
11	63,800	1983	86	---	4	6	10
12	63,800	1983	86	---	4	6	10